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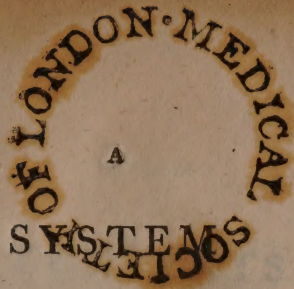
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OF

# CHEMISTRY.

IN FOUR VOLUMES.

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BY THOMAS THOMSON, M. D.

LECTURER ON CHEMISTRY IN EDINBURGH.

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VOL. III.

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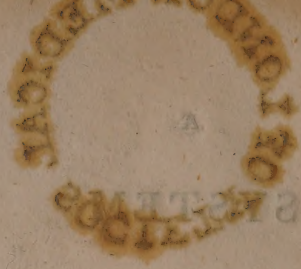
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A  
S Y S T E M  
OF  
C H E M I S T R Y .

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DIVISION II. OF BOOK II. CONTINUED.

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GENUS VII. SALTS OF IRON.

—○○○○—

THE compounds which the acids form with the oxides of iron were formerly distinguished in chemistry by the epithet *martial*, because Mars was the title given by the alchemists to iron. The most important of these salts have been long known. No metal attracts oxygen and combines with acids with more facility than iron; many of its salts therefore are found ready formed, or at least are often formed during the multiplicity of operations to which this very useful metal is exposed. Some of these salts have been long of great importance in manufactures. They form the basis of writing ink and of the black dye, and are employed also to communicate several other colours to cloth.

Chap. III.

Iron is capable of combining with two doses of oxygen, and several of the acids unite with each of its

Book II.  
Division II.

oxides. There are therefore two sets of salts which have iron for their basis ; one set containing the black oxide, the other the red. The last of these sets was scarcely attended to by chemists, till Mr Proust published his *Researches on Prussian Blue* in 1797 ; in which he described the properties of the salt composed of the red oxide of iron and sulphuric acid ; which, according to the rule formerly laid down, I shall call *oxy-sulphat of iron*. Since that time Mr Davy has ascertained the existence of several more of these salts.

The salts of iron may be distinguished by the following properties :

Characters.

1. They are almost all soluble in water ; and in general the solution has a greenish or yellowish red colour, and an astringent taste.

2. The triple prussiate occasion in these solutions a precipitate of a deep blue, or at least which acquires that colour on exposure to the atmosphere.

3. Hydro-sulphuret of potass occasions a black precipitate.

4. Sulphurated hydrogen renders the solution nearly colourless, but occasions no precipitate.

5. Gallic acid, or the infusion of nutgalls, occasions a black or purple precipitate, at least if the solution has been for some time exposed to the air.

#### *Sp. 1. Sulphated Iron.*

CONCENTRATED sulphuric acid acts but very slowly upon iron, unless it be assisted by heat. In that case the metal is oxidated, and sulphurous acid gas exhaled. But diluted sulphuric acid dissolves iron with great rapidity, and abundance of hydrogen gas is emitted. In this case the water is decomposed ; its oxygen com-



lines with the iron, while its hydrogen is emitted. The solution has a green colour, and when evaporated immediately, yields crystals of *sulphat* of iron; but if allowed to remain exposed to the atmosphere, it gradually attracts more oxygen, and is converted into *oxy-sulphat*, unless it contains an excess of acid; which retards, and when sufficiently abundant, prevents the change.

I. *Sulphat of iron*. This salt was known to the ancients, and is mentioned by Pliny under the names of *misy*, *sory*, and *calchantum*\*. In commerce it is usually denominated *green vitriol* or *copperas*. It is not prepared by dissolving iron in sulphuric acid, but by moistening the sulphurets of iron, which are found native in abundance, and exposing them to the open air. They are slowly covered with a crust of sulphat of iron, which is dissolved in water, and afterwards obtained in crystals by evaporation. Sometimes the salt is found ready formed, either in a state of solution in water or mixed with decayed pyrites.

Preparation.

Sulphat of iron has a fine green colour. Its crystals are transparent rhomboidal prisms, the faces of which are rhombs with angles of  $79^{\circ} 50'$  and  $100^{\circ} 10'$ , inclined to each other at angles of  $98^{\circ} 37'$  and  $81^{\circ} 23' 4$ . It has a very strong styptic taste, and always reddens vegetable blues. Its specific gravity is 1.8399†.

Properties.

It is soluble in about two parts of cold water, and in  $\frac{3}{4}$ ths of its weight of boiling water. It is insoluble in alcohol. When exposed to the air, its surface gradually becomes opaque, and is covered with a yellow powder;

\* Lib. xxxiv. c. 12.

† Haüy, *Jour. de Min. An.* v. 542.

‡ Hassenfrätz, *Ann. de Chim.* xxviii. 12.

Book II.  
Division II.

because it absorbs oxygen, and is partially converted into oxy-sulphat. This change takes place much more rapidly and completely if the salt be moistened with water. The cause of these phenomena was first explained by Scheele.

When heated it melts, gradually loses its water of crystallization, and by a strong heat sulphurous acid is driven off, and there remains behind a red powder, formerly known by the name of *colcothar of vitriol*, which seems to be a mixture of brown oxide of iron and oxy-sulphat. When this salt is distilled, there comes over first water slightly acidulated with sulphuric acid, and afterwards a very strong fuming acid, formerly known by the name of *glacial oil of vitriol*, and which is now known to be a compound of sulphuric and sulphurous acids. The residuum is the same mixture of oxide and oxy-sulphat which is obtained by calcination in the open fire. This decomposition, which sulphat of iron undergoes when heated, enables it in many cases, in a high temperature, to act nearly the same part as sulphuric acid. Hence it is often employed by manufacturers to disengage the weaker acids from their bases.

This salt, according to Bergman, is composed of

Composi-  
tion.

39 acid

23 oxide

38 water

100 \*

According to Kirwan, of 26 acid

28 oxide

8 water of composition

38 water of crystallization

---

100 \*

It cannot be doubted, I think, that the black oxide of iron is capable of combining intimately with water, and of forming a *hydrat*, as well as the oxide of copper. The colour of this hydrat is *green*; hence the reason that the black oxide of iron, when precipitated from acids by means of alkalies, has a green colour. It is in the state of hydrat. When the water is driven off by heat, the oxide assumes its natural black colour. The oxide, which constitutes a part of the sulphat of iron, is also combined with water, and in the state of a hydrat. Mr Kirwan, therefore, has, with great propriety, distinguished between the water of crystallization and that part which is a necessary constituent of the salt.

The sulphat of iron is decomposed by the alkaline phosphats and borats, and by the greater number of those salts whose base forms an insoluble compound with the sulphuric acid, as nitrat of silver, of lead, of barytes, &c.

2. *Oxy-sulphat of iron*. This salt exists ready formed in what is called the *mother water of vitriol*, or the brown liquid which remains after all the sulphat of iron has been extracted by crystallization from those waters which contain it. The properties of this salt were first accurately described by Mr Proust. It may be formed by exposing the solution of sulphat of iron to the open air

---

\* On *Mineral Waters*, Table iv.



Book II.  
Division II.

for some time, or by pouring into it nitric acid, and applying heat\*.

This salt has a red colour. It does not afford crystals; and when evaporated to dryness, soon attracts moisture, and becomes again liquid. It is exceedingly soluble in water, and also in alcohol. By this last liquid it may be separated from the sulphat of iron, with which it is always mixed in the *vitriol* of commerce. When exposed to the air, it gradually deposits red oxide, or rather oxy-sulphat with excess of base.

How changed into sulphat,

A great number of substances have the property of depriving this salt of its excess of oxygen, and of converting it into sulphat of iron. This is the case with iron. When the solution of oxy-sulphat is mixed with iron-filings, and kept for some time in a well-covered vessel, part of the iron is dissolved by abstracting the second dose of oxygen from the oxide, and the whole is converted into sulphat. The same change is produced by tin, and probably also by all the salts of tin which contain that metal combined with a minimum of oxygen. Sulphurated hydrogen produces that change instantaneously when made to pass through a solution of oxy-sulphat\*. That gas has the property of reducing the oxides of iron to a minimum of oxygen; but it does not bring them to the metallic state. Hence the reason that it does not precipitate iron from its solution in acids.

On the other hand, all those bodies which part with oxygen very readily, convert the sulphat of iron into

---

\* During this change a quantity of ammonia is also formed. Hence not only the nitric acid but some water also is decomposed.—See Davy's *Researches*, p. 157.

† Proust, *Ann. de Chim.* xxiii. 23.

oxy-sulphat. Hence this change is produced by the nitric and oxy-muriatic acids, by the oxy-muriats, the muriat of gold, &c.

Absorption  
of nitrous  
gas.

The solution of sulphat of iron has the property of absorbing a great quantity of nitrous gas, and at the same time it acquires a yellowish colour. When this solution is heated without being exposed to the air, the greatest part of the nitrous gas is driven off unchanged; but a small portion of it is decomposed, a little red oxide of iron is precipitated, and some ammonia formed, owing to the decomposition of a little of the water of the solution, and the combination of its hydrogen with the azot of the nitrous gas. From the experiments of Mr Davy, it appears that 910 parts of a solution of sulphat of iron, of the specific gravity 1.4, absorb 5.72 parts of nitrous gas; 4.28 of these are emitted unaltered on the application of heat, and 1.44 are decomposed. This ingenious gentleman calculates that 1 part of water was also decomposed; that the oxygen furnished by these two bodies amounted to 1.65, and that it combined with 4.1 parts of black oxide, and occasioned the precipitation of 5.75 parts of brown oxide, which was doubtless in the state of oxy sulphat, with excess of base. Hence the ammonia formed must have amounted to about 0.8 \*. The oxy-sulphat of iron has not the property of absorbing nitrous gas †.

### *Sp. 2. Sulphite of Iron.*

SULPHUROUS ACID attacks iron with rapidity, much heat is produced, and the solution assumes at first a brown colour, which gradually passes into a green.

\* Davy's *Researches*, p. 170. † Ibid.

Book II.  
Division II.

During this solution no hydrogen gas is emitted except a few bubbles at first. The iron is oxidated at the expence of the acid, part of which is decomposed; its oxygen combines with the iron and converts it into black oxide, while its sulphur combines with the sulphite of iron as it forms. The salt, therefore, which is obtained by this process, is not pure sulphite of iron, but that salt combined with sulphur. These phenomena were first described by Berthollet \*. When sulphuric acid or muriatic acid is poured into this solution the sulphurous acid is disengaged with effervescence; and if these acids be added in sufficient quantity a portion of sulphur is precipitated.

When the solution is exposed to the air, crystals of sulphite of iron are formed, and at the same time a red powder is deposited, probably consisting of *oxy-sulphite* of iron with excess of base, and combined with sulphur. The crystals dissolved in water and exposed to the air are gradually converted into sulphat of iron. †.

Thus there are two varieties of sulphited iron, *simple sulphite* and *sulphurated sulphite*. The first of these is insoluble in alcohol; but that liquid dissolves the second: the first, when exposed to the air, is converted into sulphat, but the second remains unaltered ‡.

### Sp. 3. *Nitrated iron.*

NITRIC ACID acts with great energy upon iron, a violent effervescence takes place, nitrous gas is emitted in abundance, the iron is generally oxidated to a maximum, and a red powder precipitates, consisting probably of oxy-nitrat with excess of base. These phenomena have been long known; but it was not till after

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\* *Ann. de Chim.* ii. 58.

† Fourcroy, vi. 200.

‡ *Ibid.*



Mr Proust's *Researches on the Prussiate of Iron* that the existence of two salts consisting of this acid, combined with each of the oxides of iron, was well understood by chemists. It is the *oxy-nitrat* of iron which is obtained by the usual process. Mr Proust merely announced the existence of the simple nitrat, but it has since been examined by Mr Davy.

Formation.

1. *Nitrat of iron.* When nitric acid of the specific gravity 1.16 is poured upon iron, it acts upon the metal but slowly, no gas being given out for some time. The solution becomes of a dark olive brown in consequence of the nitrous gas which it holds in solution; but when exposed to the air, it becomes pale, because that gas combines with oxygen and is converted into nitric acid. When alkalies are poured into it, a pale green precipitate falls, consisting of iron oxidated to a minimum. This solution absorbs nitrous gas. It cannot be concentrated, nor even heated, without being converted into oxy-nitrat\*.

2. *Oxy-nitrat of iron.* This is the salt obtained when iron is treated with strong nitric acid, or when the nitrat is heated or left exposed to the air. The solution is of a brown colour, and cannot be crystallized. When evaporated, it lets fall a red powder, not afterwards soluble in nitric acid; and sometimes when concentrated assumes the form of a jelly. When evaporated to dryness, the acid is disengaged, and the oxide remains in the form of a fine red powder, insoluble in nitric acid. Hence solution in nitric acid, evaporating to dryness, and digesting the residuum in water, is the method recommended by Bergman, and commonly prac-

---

\* Davy's *Researches*, p. 187.

Book II.  
Division II.

tised by chemists to separate iron from earths. The iron and earths are first dissolved together in nitric acid; by the evaporation to dryness, the nitrat of iron is decomposed, while the earthy nitrats remain unaltered. They are of course dissolved by the water, but the red oxide of iron is left untouched.

How cry-  
stallized.

Vauquelin has lately discovered a method of obtaining the oxy-nitrat of iron in crystals. When concentrated, nitric acid is kept for some months in contact with the black oxide of iron, solution slowly takes place, and crystals nearly colourless are formed, which have the figure of rectangular four-sided prisms, terminated by dihedral ridges. These crystals have an acrid and inky taste, and are very deliquescent. Their solution in water has a red colour, and the alkalies precipitate from it red oxide of iron\*.

#### *Sp. 4. Muriated Iron.*

MURIATIC ACID attacks iron even with more rapidity than the sulphuric; hydrogen gas is emitted in consequence of the decomposition of water, and the iron is oxidated and dissolved. This acid dissolves likewise the oxides of iron much more readily than any other, and for that reason it is usually employed to take out iron-marks from linen, and to remove particles of rust, which often adhere with great obstinacy to glass vessels. Muriatic acid combines both with the black and brown oxides of iron, and forms with each of them a peculiar salt, the properties of which have been lately described by Mr Davy. Their existence had been previously pointed out by Proust. The common muriat

---

\* Fourcroy, vi. 205.

of iron, usually obtained by dissolving iron or its oxides in muriatic acid, is a mixture of these two salts.

1. *Muriat of iron.* When iron-filings are dissolved in muriatic acid, the solution, provided it be excluded from the air, is of a pale green colour, and yields, when evaporated, crystals of muriat of iron almost white, which are extremely soluble in water, but insoluble in alcohol. The solution attracts oxygen from the air and from nitric acid. It absorbs nitrous gas even in greater quantity than sulphat of iron, and acquires, when saturated, a dark brown colour, and a much more astringent taste than muriat of iron in its usual state. When heated, the greatest part of the gas is driven off, some red oxide of iron is precipitated, and some ammonia formed, precisely as happens to a solution of sulphat of iron impregnated with nitrous gas\*.

2. *Oxy-muriat of iron.* This salt may be formed by dissolving the red oxide of iron in muriatic acid, or by treating the muriat of iron with nitric acid. The solution of this salt is of a deep brown; its odour is peculiar, and its taste, even when much diluted with water, is exceedingly astringent. When evaporated to dryness, it yields an uncrystallizable orange-coloured mass, which deliquesces in the air, and is soluble in alcohol. This salt gives a yellow tinge to animal and vegetable substances, as is the case with oxy-muriatic acid. When sulphuric acid is poured upon it, the odour of oxy-muriatic acid is perceptible. This salt does not absorb nitrous gas. When sulphurated hydrogen gas is made to pass through it, part of the oxygen is abstracted, and the salt is converted into muriat of iron†.

Action on  
animals and  
vegetables.

---

\* Davy, p. 180.

† Ibid. p. 181.



Book II.  
Division II.

When this salt is distilled, oxy-muriatic acid passes over, and the iron is reduced to the state of black oxide. This acid is also formed and exhaled during the solution of brown oxide of iron in muriatic acid, at least if the solution be promoted by the application of heat.

### Sp. 5. *Phosphated Iron.*

PHOSPHORIC ACID has but little action upon iron. However, if that metal remain exposed to the contact of phosphoric acid, or even to the solutions of salts which contain that acid, it is gradually oxidated, and converted into phosphat of iron. The properties of phosphated iron have not been examined with attention. Scheele has shewn that the acid combines with both oxides; and forms of course both a *phosphat* and *oxy-phosphat* of iron. Fourcroy and Vauquelin have lately ascertained that there are two varieties of this last salt; one which had been already described by Bergman, Meyer, Klaproth, and Scheele, and another with excess of base, and consequently a *sub-oxy-phosphat*, which these philosophers first observed.

1. *Phosphat of iron.* When sulphat of iron dissolved in water is mixed with a solution of phosphat of potass, a blue powder precipitates, which is phosphat of iron. This powder is insoluble in water, and does not lose its colour when exposed to the air\*. This salt is found native, and constitutes the colouring matter of a blue mineral called *native prussian blue*, found in bogs, and first analysed by Klaproth. *Native prussian blue*, as it is called, when dry out of the earth,

Native  
prussian  
blue.

---

\* Scheele, *Crell's Annals*, i. 115. Engl. Trans.

is at first often colourless ; but when exposed to the air, it becomes blue. The cause of this change has not been ascertained.

2. *Oxy-phosphat of iron.* This salt may be readily procured by mixing together the solutions of oxy-muriat of iron and phosphat of potass or soda. A white powder immediately falls, which is oxy-phosphat of iron.

This salt, like almost all the phosphats, is soluble in acids, but precipitated undecomposed by ammonia. It is almost insoluble in water, as it requires more than 1500 parts of that liquid to dissolve one part of oxy-phosphat. When heated violently, it melts into an ash-coloured globule\*. When mixed with charcoal, and heated to redness, it is converted into phosphuret of iron.

3. *Sub-oxy-phosphat of iron.* When the oxy-phosphat of iron is treated with the pure fixed alkalies, a red, or rather brownish-red, powder is separated, while the alkali combines with phosphoric acid. This powder was examined by Fourcroy and Vauquelin, and found by them still to contain a portion of acid. It is therefore merely oxy-phosphat with excess of base. This salt is scarcely soluble in acids or in water ; but it dissolves readily in the white of an egg, or in the serum of blood, and communicates to these liquids a brown or red colour. Its solubility is increased, and its colour heightened, by the presence of a portion of fixed alkali†. This is the salt which gives a red colour to the blood.

#### Sp. 6. *Fluated Iron.*

FLUORIC ACID attacks iron with violence ; hydrogen

\* Bergman, iii. 118.

† Fourcroy, ix. 152.

Book II.  
Division II.

gas is emitted, and the metal oxidated and dissolved. The solution has an inky taste, and when evaporated does not crystallize, but assumes the form of a jelly. In this state it is undoubtedly an *oxy-fluat* of iron. Heat decomposes it by expelling the acid. The same effect is produced by sulphuric acid. Fluoric acid also dissolves the brown oxide of iron, and forms the same salt\*.

*Sp. 7. Borat of Iron.*

BORACIC ACID acts very feebly upon iron; but borat of iron may be obtained very readily by pouring liquid borat of soda into a solution of sulphat of iron. A pale yellow powder immediately precipitates, which is the salt required. This salt is insoluble in water. Before the blow-pipe it melts readily into a globule of glass†.

*Sp. 8. Carbonat of Iron.*

LIQUID carbonic acid, when kept in contact with iron, attacks it slowly, and dissolves a sufficient quantity of it to acquire a sensibly chalybeate taste. When exposed to the air, the iron is gradually precipitated in the state of black oxide‡. This carbonat often exists native in mineral waters. It may be obtained also by precipitating sulphat of iron by means of an alkaline carbonat. In that case it is always in the form of a green mass.

RUST may be considered as an oxy-carbonat of iron; for it consists of the brown oxide of that metal combi-

\* Scheele, i. 34.

† Id. Crell's *Annals*, i. 114. Engl. Trans.

‡ Bergman, i. 33.



ned with carbonic acid. Hence it dissolves in acids with effervescence, and when heated gives out carbonic acid gas : the residuum in that case is black oxide of iron\*. From the experiments of Bergman carbonat of iron seems to be composed of about

$$\begin{array}{r} 24 \text{ acid} \\ 76 \text{ oxide} \\ \hline 100 \dagger \end{array}$$

### Sp. 9. *Arseniated Iron.*

ARSENIC ACID dissolves iron when assisted by a digesting heat; and if the experiment be made in an open vessel, the solution at last assumes the form of a jelly; but in a close vessel this does not happen. When one part of iron-filings and four parts of arsenic acid are distilled together to dryness, inflammation takes place, and at the same time both arsenic and white oxide of arsenic are sublimed‡. Arsenic acid, as we see from these facts, is capable, like other acids, of combining with both the oxides of iron, and of forming *arseniat* of iron and *ox-arseniat* of iron. Both of these salts have been found native in Cornwall, and have been lately described and analysed with great accuracy by Bournon and Chenevix.

1. *Arseniat of iron.* This salt may be formed by pouring arseniat of ammonia into sulphat of iron. The salt precipitates in the state of a powder, insoluble in water. It exists native crystallized in cubes, which in some instances have their alternate angles truncated. Their colour is usually dark green, and their specific

\* Fourcroy, vi. 215.

† Bergman, ii. 392.

‡ Scheele, i. 177.

Book II.  
Division II.

Composi-  
tion.

gravity 3 \*. When heated, the iron attracts oxygen from the acid, and passes to the state of red oxide, while white oxide of arsenic sublims. This native salt is usually contaminated with a little copper. The artificial arseniat, according to the analysis of Chenevix, is composed of . . . . . 38 acid

43 oxide

19 water

---

100

The native (abstracting the impurities) was found by the same accurate chemist to be composed of about

36 acid

52 oxide

12 water

---

100 †

2. *Ox-arseniat of iron.* This salt may be formed by precipitating oxy-sulphat of iron with arseniat of ammonia, or by boiling the arseniat of iron in nitric acid. The native arseniat is sometimes found converted into this salt in consequence of the absorption of oxygen from the air. It has then a brownish-red colour. According to the analysis of Chenevix, the artificial ox-arseniat is composed of 42.4 acid

37.2 oxide

20.4 water

---

100.0 ‡

---

\* Bournon, *Phil. Trans.* 1801, p. 190.

† Ibid. p. 220.

‡ Ibid. p. 223.

*Sp. 10. Tungstat of Iron.*

THIS salt exists native, and is known to mineralogists by the name of *Wolfram*. It may be formed by precipitating sulphat of iron by means of the tungstats. It is an insoluble powder, possessing properties similar to native tungstat of iron. As this native salt contains also manganese, and is not therefore a pure tungstat of iron, it will be proper to defer the description of it to the SECOND PART of this Work.

*Sp. 11. Molybdat of Iron.*

THE alkaline molybdates precipitate iron brown from its solution in acids\*.

*Sp. 12. Acetite of Iron.*

THE acetous acid dissolves iron with rapidity, producing an effervescence, and, like the other acids, it forms a salt with each of the oxides of that metal; but the properties of these salts have not been examined with attention.

*Acetite of iron* yields by evaporation crystals of a green colour, in the form of small prisms. It has a sweetish styptic taste, and its specific gravity is 1.368†. By exposure to the air, or by the application of heat, it is converted into *oxacetite*.

*Oxacetite of iron* is a reddish-brown solution, incapable of yielding crystals, and assumes the form of a jelly when evaporated. It is deliquescent. This salt is much employed by calicoe printers, because it is more easily decomposed than any other of the oxygenated salts of

\* Scheele, i. 248.

† Hassenfratz, *Ann. de Chim.* xxxviii. 12.



Book II.  
Division II.

iron. They prepare it either by mixing together sulphat of iron and acetite of lead, and leaving the solution exposed to the air, or by dissolving iron in an impure acetous acid, obtained by distilling wood.

The acetites of iron are decomposed by heat, and the iron left in the state of black oxide.

*Sp. 13. Oxalated Iron.*

OXALIC ACID attacks iron rapidly, and dissolves it with effervescence and forms a peculiar salt with each of its oxides.

*Oxalat* is obtained by dissolving iron or its black oxide in that acid, and evaporating the solution. Prismatic crystals of a green colour and sweet astringent taste are formed, very soluble in water with an excess of acid, which fall to powder when heated. They are composed of . . . . . 55 acid

45 oxide

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100

*Oxygenated oxalat* may be obtained by dissolving red oxide of iron in oxalic acid, or by exposing the first salt to the air in a digesting heat. It has the form of a yellow powder, scarcely soluble in water, and incapable of crystallizing\*.

Oxalic acid readily dissolves the oxide of iron even when combined with gallic acid. Hence it is often used to take spots of ink out of linen; and super-oxalat of potass is usually sold in this country for that purpose, under the name of *essential salt of lemons*.

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\* Bergman, i. 268.

*Sp. 14. Tartrited Iron.*

TARTAROUS ACID dissolves iron with effervescence, and combines with each of its oxides.

*Tartrite of iron* may be formed, according to Retzius, by pouring tartarous acid into sulphat of iron, and applying heat to the solution. Lamellar crystals are formed, sparingly soluble in water, which possess the properties of tartrite of iron.

*Oxy-tartrite* is usually formed when iron is dissolved in tartarous acid and heat applied to the solution. It has a red colour, does not crystallize, but assumes the form of a jelly when evaporated.

*Sp. 15. Triple Tartrite of Iron.*

THIS triple salt was formerly called *tartarised tincture of Mars*, *chalybeated tartar*, and *tartarised iron*. It may be formed by boiling two parts of tartar and one of iron-filings, previously made up into a paste, in a proper quantity of water. The liquor by evaporation deposits crystals, which form the salt wanted.

*Sp. 16. Citrat of Iron.*

THIS salt has only been examined by Vauquelin. Citric acid dissolves iron slowly; the solution has a brown colour, and deposits small crystals of citrat of iron. When evaporated, it becomes black like ink, ductile while hot, but brittle while cold. This mass is evidently oxy-citrat of iron. It is astringent, and very soluble in water.

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Citrat of iron, according to Vauquelin, is composed  
of . . . . . 69.62 acid

30.38 oxide

100.00 \*

*Sp. 17. Malat of Iron.*

A BROWN solution not crystallizable †.

*Sp. 18. Gallat of Iron.*

MR PROUST first observed, that the gallic acid does not occasion any precipitate when poured into salts of iron containing that metal in the state of black oxide. Hence it follows that the gallat of iron, if it be formed in these cases, is very soluble in water and without colour; but when gallic acid is poured into the oxygenated salts of iron, the solution becomes black, and a black precipitate, composed of gallic acid and red oxide of iron, immediately begins to fall; but it is so very fine and light, that the greater part of it remains long suspended; and if a quantity of mucilage or syrup be mixed with the solution, the precipitate remains suspended altogether. It is this solution which constitutes writing ink. But ink is usually made by mixing the sulphat of iron of commerce with a saturated solution of nutgalls. Now the sulphat of commerce is a mixture of sulphat and oxy-sulphat of iron. That part of the iron which is in the state of sulphat forms at first a colourless solution, but by attracting oxygen from the atmosphere, it gradually becomes black. Hence the reason that ink is often pale at first, but becomes black

Writing  
ink.

\* Fourcroy, vii. 209.

† Scheele, Crell's *Annals*, ii. 10. Engl. Trans.



when the writing dries, in consequence of the absorption of oxygen.

Gallat of iron is soluble in acids without decomposition, but it loses its colour in very strong acids. Hence the reason that these acids destroy the colour of writing.

*Sp. 19. Benzoat of Iron.*

THIS salt forms yellow crystals. It has a sweet taste. It is soluble in water and alcohol. It effloresces in the air. Heat disengages the acid \*.

*Sp. 20. Succinat of Iron.*

SUCCINIC ACID dissolves the oxide of iron, and yields by evaporation small brown transparent radiated crystals †.

*Sp. 21. Prussiated Iron.*

THE combination formed between the prussic acid and iron has been the object of a great many researches, and has given occasion to several curious and important discoveries. We are indebted to Mr Proust for the fact that the prussic acid, like all other acids hitherto tried, is capable of forming a peculiar salt with each of the oxides of iron.

1. *Prussiat of iron.* This salt may be formed by pouring triple prussiat of potass into a solution of sulphat of iron. The salt precipitates in the form of a white powder. It is not altered by sulphuric and muriatic acids. When exposed to the air it absorbs oxygen with great rapidity, and passes to the state of oxy-

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\* Trommsdorf, *Ann. de Chim.* xi. 314.

† Wenzell's *Verwand.* p. 331.

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prussiat. Oxy-muriatic and nitric acids produce the same change.

2. *Oxy-prussiat of iron.* This salt is formed when triple prussiat of potass is poured into oxy-sulphat of iron, or into the solution of any oxygenated salt of iron. A beautiful blue precipitate appears, which is the salt. It is not altered by the acids. Sulphurated hydrogen gas converts it into prussiat by absorbing oxygen. When it is mixed with iron-filings, and kept in water in a close vessel, it is also converted into prussiat, the iron absorbing the second dose of oxygen from the red oxide \*.

*Sp. 22. Sebat of Iron.*

SEBACIC ACID dissolves iron, and forms with its oxide deliquescent needle-shaped crystals. It does not precipitate the solutions of iron in sulphuric and nitric acids†.

GENUS VII. SALTS OF TIN.

THOUGH several of the salts of tin are of great importance in the art of dyeing, and have been known to manufacturers ever since the discovery of the scarlet dye, of which the oxide of tin constitutes a necessary ingredient, it is only of late that the nature and constitution of these salts have been examined with any kind of precision, and that a satisfactory explanation has been given of the curious properties which some of these salts possess, and the great changes to which they are liable. For the progress which this branch of the science has made, we are chiefly indebted to Adet, Pelletier, and Proust.

\* Proust, *Ann. de Chim.* xxii. 88.

† Crell, *Phil. Trans.* 1782.

Tin, like iron, combines with two doses of oxygen, and forms two distinct oxides, with each of which several of the acids are capable of combining; and those which contain the metal oxidated to a minimum are extremely ready to absorb oxygen, and to pass into the state of oxygenated salts. The salts of tin may be distinguished by the following properties:

1. Most of them are more or less soluble in water, and the solution has usually a yellowish or brownish tinge. Characters.

2. Triple prussiat of potass occasions a white precipitate when dropt into these solutions.

3. Hydrosulphuret of potass occasions a black precipitate; sulphurated hydrogen gas, a brown precipitate.

4. Neither gallic acid nor the infusion of nutgalls occasions any precipitate.

5. When a plate of lead is put into some solutions of tin, that last metal is separated either in the state of metal, or of white oxide: but this does not happen in every solution of tin.

6. When muriat of gold is poured into solutions containing tin combined with a minimum of oxygen, a purple-coloured precipitate falls.

The salts of tin were formerly distinguished by the epithet *jovial*, because *Jupiter* was the name by which the alchymists distinguished that metal.

#### Sp. 1. Sulphat of Tin.

SULPHURIC ACID is capable of dissolving tin; but the properties of the compounds which it forms have not been examined with accuracy. Kunkel, Wallerius, and Monnet, the chemists who have paid the greatest attention to the action of sulphuric acid on tin, attempt-



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ed the solution by means of heat. In that case the acid is decomposed, sulphurous acid exhaled, and even sulphur developed if the heat be long enough continued. The metal is oxidated to a maximum, and the *oxy-sulphat* obtained is not crystallizable; but when evaporated assumes the form of a jelly; and when water is poured into the solution, the salt precipitates in the state of a white powder.

But if the action of the acid is not assisted by heat, or if tin combined with a minimum of oxygen be dissolved in it, in either of these cases a *sulphat* of tin is formed, which yields, when evaporated, crystals in the form of fine needles, as was observed long ago by Monnet.

[*Sp. 2. Sulphite of Tin.*]

THE action of sulphurous acid upon tin has been examined lately by Fourcroy and Vauquelin, during their experiments on the combinations which that acid is capable of forming. When a plate of tin is plunged into liquid sulphurous acid, it assumes a yellow colour, and afterwards becomes black. A black powder is precipitated, which is sulphuret of tin. A portion of the acid is decomposed; the tin is partly oxidated, and combined with the remainder of the acid, and partly precipitated in the state of sulphuret combined with the sulphur of the decomposed acid. There remains in solution sulphite of tin combined with a portion of sulphur; for sulphur precipitates when sulphuric acid is added to the solution\*.

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\* Fourcroy, vi. 39.

*Sp. 3. Nitrated Tin.*

Chap. III.

Action of  
nitric acid  
on tin.

NITRIC ACID acts with amazing energy upon tin, and converts it into an oxide with the evolution of a great deal of heat; but there seems to be but a very feeble affinity between that acid and the oxides of tin. Hence the union which they form is but of transient duration; the oxides separating when any attempt is made to concentrate the solution. This has been long known to chemists, and has occasioned a variety of attempts to make the solution of tin in nitric acid more permanent; but these attempts, as might have been expected, have not been attended with success.

When nitric acid of the specific gravity 1.114 is poured upon tin, the metal is dissolved rapidly with effervescence and a great elevation of temperature, which ought to be moderated by plunging the vessel containing the mixture in cold water. In this case the oxygen is chiefly furnished by the water, and the tin is only combined with a minimum of oxygen. The solution, therefore, which is of a yellow colour, is a real *nitrat* of tin. It becomes gradually opaque, and deposits a white powder, which is an oxide of tin with a minimum of oxygen, as Proust has demonstrated. This oxide separates in greater abundance if the solution be heated. During the solution of the tin a quantity of ammonia is formed, as Morveau first observed. When potass is dropt into the liquid, this ammonia becomes sensible by its odour. Hence we see that, during the solution, both water and nitric acid have been decomposed; their oxygen combined with the tin, and the hydrogen of the one uniting with the azot of the other, formed ammonia. If a little nitric acid be poured in,

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and heat applied, the tin precipitates oxidated to a maximum\*.

When nitric acid, of the specific gravity 1.25, is poured upon tin, a very violent action takes place, the metal is oxidated to a maximum, and the whole of it separates from the liquid. Hence we see that there is no *oxy-nitrat* of tin; that metal, when combined with a maximum of oxygen, not being susceptible of entering into combination with nitric acid. When the liquid is evaporated, *nitrat* of ammonia is obtained. Morveau found, that 1 part of strong nitric acid and  $1\frac{1}{2}$  part of tin, when treated in a retort, gave out no gas, notwithstanding the violence of their action. Upon examining the liquid, he found that the ammonia formed amounted to  $\frac{1}{20}$  of the weight of the whole†. Hence we see that, during the oxidation, both the acid and the water are decomposed; and that they are decomposed in such proportions, that their hydrogen and azot combine, and form ammonia, while the whole of their oxygen unites with the tin.

#### *Sp. 4. Muriated Tin.*

MURIATIC ACID dissolves tin in considerable quantity when its action is assisted by heat. The water of the acid is decomposed, its oxygen combines with the tin, while the hydrogen is emitted in the form of gas. This gas has usually a fetid smell, owing, according to Mr Proust, to a quantity of arsenic which it holds in solution, and which is partly deposited on the sides of the jars in which the gas is kept. During the solution of the tin, the arsenic which it usually contains is precipi-

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\* Proust, *Jour. de Phys.* li. 173.

† *Encyc. Method. Chim.* i. 632.



tated in the metallic state in the form of a black powder; so that the quantity of arsenic contained in tin may be ascertained by dissolving it in muriatic acid, provided that portion which is carried off by the hydrogen gas be also taken into account\*. Muriatic acid combines with both the oxides of tin, and forms with them permanent salts.

1. *Muriat of tin.* This is the salt obtained by dissolving tin in about four times its weight of muriatic acid. The solution has a brownish-yellow colour, and yields when evaporated small needle-shaped crystals, soluble in water, and somewhat deliquescent. Their specific gravity is 2.2932 †.

This salt has a strong affinity for oxygen, and absorbs it with avidity from the air, from oxy-muriatic acid, and from nitric acid, and is converted into oxy-muriat of tin, as Pelletier first observed. It absorbs oxygen also from arsenic acid, and the white oxide of arsenic. When these bodies are treated with muriat of tin, they are precipitated, completely deprived of oxygen, in the state of a black powder. Molybdic acid and yellow oxide of tungsten, or their combinations, when dropt into a solution of muriat of tin, immediately assume a blue colour, being changed into oxides with a minimum of oxygen. The red oxide of mercury, the black oxide of manganese, the white oxide of antimony, the oxides of zinc and of silver, are likewise deprived of their oxygen by this salt, and reduced to the metallic state. The oxygenated salts of iron and copper are also reduced to salts with a minimum of oxygen, and the

Affinity for  
oxygen.

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\* Proust, *Jour. de Phys.* li. 175.

† Hasenfratz, *Ann. de Chim.* xxviii. 12.

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muriat of gold occasions a purple precipitate, consisting of gold reduced to the state of purple oxide. For these interesting results we are indebted to Pelletier and Proust. They afford a sufficient key to explain all the singular changes produced upon the greater number of metallic salts by this muriat\*.

Preparation.

2. *Oxy-muriat of tin.* This salt may be formed very conveniently by the process first proposed by Pelletier, which consists in causing oxy-muriatic acid gas to pass into a solution of muriat of tin till it be saturated, and then to expel the excess of acid by heat. But it was known long before this process was thought of, and was usually distinguished by the name of *smoking liquor of Libavius*; because Libavius, a chemist of the 16th century, was the discoverer of it. When equal parts of amalgam of tin† and oxy-muriat of mercury are triturated together, and then distilled in a retort with a very moderate heat, there passes first a colourless liquid, consisting chiefly of water, and afterwards a white vapour rushes all of a sudden into the receiver. This vapour condenses into a transparent liquid, which exhales a heavy dense smoke when exposed to the air, but does not smoke when confined in close vessels. This is the fuming liquor of Libavius, or oxy-muriat of tin.

The theory of the process is obvious: The tin abstracts oxygen from the mercury, and at the same time combines with the muriatic acid. Muriats of mercury and of tin are also formed, and line the neck of the retort mixed with a quantity of pure mercury; and there

\* Pelletier, *Ann. de Chim.* xii. 225.—Proust, *Jour. de Phys.* li. 173.

† Composed of two parts of tin and one of mercury.

remains behind an amalgam of tin, covered with a crust of muriat of tin\*. It had been long known that this liquid contained muriatic acid and tin; but Adet was the first who demonstrated that the tin was oxidated to a maximum, and that therefore the salt was an oxy-muriat of that metal†; and his conclusions were afterwards confirmed by Pelletier‡.

The white smoke constantly exhaled by this salt, prepared according to the process of Libavius, has also been accounted for by Adet. The salt is nearly destitute of water, and in this state it is exceedingly volatile. The vapour as it rises combines with the vapour of the atmosphere, and the smoke appears at the moment of the combination. When the salt is confined in a glass jar, either in moistened air or standing over water, it condenses gradually on the sides of the jar in the form of small crystals, having imbibed the water necessary for its crystallization from the air. When thrown into water, this substance produces heat, and at the same time dissolves if the quantity of water be sufficient. Adet ascertained, that when 7 parts of water are mixed with 22 parts of fuming muriat, the mixture condenses into a solid mass. This mass melts like ice when exposed to heat, and condenses again when cooled and agitated.

Oxy-muriat of tin is capable of dissolving an additional dose of tin without effervescence or the exhalation of gas, and by that means is converted into muriat of tin. The new portion of tin in this case deprives the tin of the oxy-muriat of its second dose of oxygen. Adet, however, found, that this solution did not suc-

\* Rouelle.

† *Ann. de Chim.* i. 5.‡ *Ibid.* xii. 225.

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ceed except in the oxy-muriat, rendered solid by mixture with water, and then liquefied by heat \*.

Liquid oxy-muriat of tin yields by evaporation small crystals; and when heated sublimes in the same manner as fuming muriat. This salt is employed by dyers in great quantities, as it forms the basis of the scarlet dye. They usually prepare it by dissolving tin in nitro-muriatic acid; the consequence of which is, that the nature of the solution varies according to the proportion of the acids and the manner of dissolving the tin. In some cases, it is merely a muriat; in others, an oxy-muriat; and, generally, it consists of a mixture of the two. Hence the difficulty of which dyers complain of forming with this solution the same shade of colour in different circumstances. This would be in a great measure removed by preparing the salt according to the process recommended by Pelletier.

*Sp. 5. Phosphat of Tin.*

PHOSPHORIC ACID has scarcely any action on tin unless when it is exposed dry and mixed with that metal to the action of a strong heat. In that case, part of the acid is decomposed, its phosphorus combines with one portion of the tin and forms a phosphuret, while the oxide of tin unites with the undecomposed acid and forms a phosphat †. This salt precipitates also when the alkaline phosphats are mixed with a solution of muriat of tin: but its properties have never been examined.

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\* *Ann. de Chim.* i. 16.

† Pelletier, *Ann. de Chim.* xiii. 16.



*Sp. 6. Fluat of Tin.*

FLUORIC ACID does not attack tin; but it dissolves its oxide, and forms with it a gelatinous solution, which has a strong disagreeable taste \*. This fluat may be formed also by mixing together an alkaline fluat and the muriat of tin.

*Sp. 7. Borat of Tin.*

BORACIC ACID does not attack tin: but according to Palm, equal parts of tin-filings and boracic acid, melted together and dissolved in water, yield by evaporation transparent white polygonous crystals.

*Sp. 8. Carbonat of Tin.*

As far as is known at present, the oxides of tin do not combine with carbonic acid. Bergman failed in his endeavours to combine carbonic acid with the oxides of tin †; and when precipitated from their solution in acids by alkaline carbonats, he found that their weight received scarcely a perceptible increase ‡. Nor have the attempts of Proust to combine it with carbonic acid been attended with more success §.

*Sp. 9. Arseniat of Tin.*

WHEN tin is treated with arsenic acid in a digesting heat, it is slowly oxidated at the expence of the acid, and the solution at last assumes the form of a gelatinous mass. Arsenic acid precipitates tin from acetous acid, and the alkaline arseniats occasion a precipitate

\* Scheele, i. 34.

† Opusc. i. 37.

‡ Ibid. ii. 392.

§ Jour. de Phys. li. 167.

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when poured into muriat of tin. The precipitate is arseniat of tin in the form of an insoluble powder, which hitherto has not been examined\*.

*Sp. 10. Acetite of Tin.*

Action of  
vinegar on  
tin vessels.

ACETOUS ACID attacks tin very slowly, even when assisted by heat, and oxidates and dissolves only a small portion of it. The spontaneous action of this acid on tin vessels, when in the state of vinegar, has been lately examined by Vauquelin. The subject was of importance, because vinegar is usually measured out in tin vessels. Now, as these vessels contain always a little lead, and as the salts of lead are all poisonous, it was of consequence to determine whether the vinegar acted on the vessel, and if it did, whether its action was confined to the tin or extended also to the lead; because in this last case the vinegar would be converted into a poison. The result of his investigation was, that a small portion of tin was dissolved, and that when the lead exceeded the sixth part of the tin, a small portion of it was also dissolved at that part of the vessel only which was in contact both with the vinegar and the air†.

When acetous acid is boiled upon tin, the metal is gradually dissolved, combining with oxygen at the expence of the water. The solution has a whitish colour, and yields by evaporation small crystals. This fact, first mentioned by Lemery, had been denied by Monnet, Westendorf, and Wenzel, who could only obtain from it a gummy mass. But Morveau established the truth of Lemery's observation, by crystallizing acetite of tin

\* Scheele, i. 180.

† *Ann. de Chim.* xxxii. 243.

by spontaneous evaporation \*. It is easy to account for the different results obtained by these chemists. The crystals were no doubt *acetite* of tin, the gummy mass *oxacetite* of tin.

*Sp. 11. Oxalat of Tin.*

OXALIC ACID attacks tin when assisted by heat. The metal is first blackened, and is then covered with a white crust of oxide. The solution, which has an austere taste, by slow evaporation yields prismatic crystals; but when evaporated rapidly by means of a strong heat, it leaves a mass resembling horn †.

*Sp. 12. Tartrite of Tin.*

THE tartrite of tin has never been examined by chemists. The acid does not attack the metal, but it dissolves the oxid of tin.

*Sp. 13. Tartrite of Potass-and-tin.*

THIS triple salt may be formed by boiling together tartar and the oxide of tin in water. It is very soluble, and therefore its solution crystallizes with difficulty. No precipitate is produced in it by the alkalies or their carbonats ‡.

*Sp. 14. Benzoat of Tin.*

NEITHER tin nor its oxide is soluble in benzoic acid; but when benzoat of potass is poured into a solution of tin in nitro-muriatic acid, benzoat of tin precipitates. It is soluble in water by the assistance of

\* *Encycl. Method. Chim.* i. 23. † Bergman i. 269.

‡ Thenart, *Ann. de Chim.* xxxviii. 35.

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heat, but insoluble in alcohol, and decomposed by the action of heat \*.

*Sp. 15. Succinat of Tin.*

SUCCINIC ACID dissolves the oxide of tin when assisted by heat. The solution by evaporation yields thin, broad, transparent crystals †.

*Sp. 16. Sebat of Tin.*

TIN, by the action of sebacic acid, is corroded into a yellow powder, especially if heat be applied. The solution is turbid, and deposits gradually a yellow powder, acquiring at the same time a fine red colour. When the yellow powder is dissolved in water, a white deliquescent salt is obtained ‡.

GENUS VIII. SALTS OF LEAD.

THOUGH lead be one of the most abundant and useful metals, though it has been known from the earliest ages, and though it is without difficulty dissolved by the greater number of acids, its salts have not hitherto been much examined by chemists. This is to be regretted; because the various degrees of oxidation of which it is susceptible, afford an excellent opportunity of ascertaining how many different salts it is capable of forming with each peculiar acid; and this once known, would probably lead to some general conclusions concerning the different classes of metallic salts. The salts of lead were formerly distinguished by the name of *saturn*, the

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\* Trommsdorf, *Ann. de Chim.* xi. 315. † Wenzel's *Verwand*, p. 337.

‡ Crell, *Phil. Trans.* 1782.



title by which lead was known among the alchymists. They may be distinguished by the following properties :

1. A considerable number of them are scarcely soluble in water without an excess of acid. These before the blow-pipe yield very readily a button of lead.

2. The solution of the soluble salts of lead in water is generally colourless and transparent.

3. They have almost all less or more of a sweet taste, accompanied with a certain degree of astringency.

4. Triple prussiat of potass occasions a white precipitate when poured into solutions containing salts of lead.

5. Hydro-sulphuret of potass occasions a black precipitate. The same precipitate is produced by sulphurated hydrogen.

6. Gallic acid and the infusion of nutgalls occasion a white precipitate.

7. A plate of zinc kept in a solution of lead occasions either a white precipitate, or the lead appears in its metallic state.

Though lead is susceptible of combining with several doses of oxygen, it does not appear that each of its oxides is capable of combining with acids. As far as is known at present, it is only the oxides containing a minimum and maximum of oxygen that possess that property. None of the attempts to combine the red oxide of lead with acids have been attended with success. The white oxide combines with all acids hitherto tried; only the salts formed by means of that oxide have been hitherto examined: the combinations of the brown oxide have been almost completely overlooked. At present, therefore, we are acquainted with but few oxygenated salts of lead.

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Sp. 1. Sulphat of Lead.

SULPHURIC ACID does not attack lead while cold ; but at a boiling heat it communicates a portion of its oxygen, sulphurous acid gas is emitted, and the whole is converted into a thick white mass, which is sulphat of lead. It may be obtained readily by pouring sulphuric acid into acetite of lead, or by mixing this last salt with any of the alkaline sulphats. The sulphat of lead precipitates in the state of a white powder. This salt has but little taste. Its specific gravity is 1.8742\*. According to Kirwan, it requires 1200 parts of water to dissolve it †. But when it contains an excess of acid, it is more soluble, and yields by evaporation small white crystals, which, according to Sage, have the form of tetrahedral prisms. It is found native crystallized, according to Kirwan, in four-sided oblique angled prisms ‡, according to Haüy, in regular octahedrons §. It is insoluble in alcohol and in acetic acid.

Composition.

According to the experiments of Kirwan, it is composed of . . . . .	23.37 acid
	75.00 white oxide
	1.63 water
	<hr/>
	100.00

And 100 parts of it contain exactly 71 parts of lead in the metallic state \*\*.

In close vessels this salt endures a considerable heat

\* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† *Mineralogy*, ii. 211.

‡ Kirwan's *Min.* ii. 211.

§ *Jour. de Min. An.* v. p. 508.

\*\* Kirwan on *Mineral Waters*, Table iv.

without alteration; but on charcoal it melts, and the lead is quickly reduced. This salt is sometimes employed as a paint instead of *white lead* or the white oxide of lead.

*Sp. 2. Sulphite of Lead.*

SULPHUROUS ACID has no action whatever on lead. It absorbs oxygen from the red oxide of that metal, and is converted into sulphuric acid. But it combines with the white oxide of lead, and forms with it a sulphite, which is in the state of a white powder, insoluble in water, and tasteless. Before the blow-pipe, on charcoal, it melts, becomes yellow, and the lead is at last reduced. When heated in close vessels, it gives out water, sulphurous acid, and sulphur, and is converted into sulphat of lead\*.

*Sp. 3. Nitrat of Lead.*

NITRIC ACID dissolves lead readily when not too much concentrated. The effervescence which accompanies the solution is occasioned by the emission of nitrous gas. The white oxide of lead is dissolved by nitric acid completely, and without effervescence; but the red oxide is rendered white;  $\frac{6}{7}$ ths of its weight are dissolved, and  $\frac{1}{7}$ th is converted into brown oxide, and remains undissolved†. Hence we see that it is the white oxide of lead only which combines with nitric acid. Six-sevenths of the red oxide are decomposed; their excess of oxygen combines with the remaining seventh, and converts it into brown oxygen, while their base of white oxide combines with the acid.

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\* Fourcroy and Vauquelin, *Connaissances Chimiques*, vi. 86. † Proust.

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The solution of lead in nitric acid yields by evaporation transparent crystals, in the form of tetrahedrons truncated near their base, and likewise of six-sided truncated pyramids, having their faces alternately large and small\*. These crystals have a sweet and at the same time an acrid taste. Their specific gravity is 4.068†. They are very soluble in water, like all the nitrates. When heated they decrepitate, and then undergo a kind of detonation, emitting very brilliant sparks‡. When they are triturated with sulphur in a hot mortar, a feeble detonation is produced, and the lead is reduced to the metallic state§.

This salt is decomposed by the alkalies, which combine with its acid, while the white oxide of lead is precipitated. Sulphuric, sulphurous, and muriatic acids combine with its base, and the new formed salt precipitates in the state of a white powder.

#### *Sp. 4. Muriated Lead,*

MURIATIC ACID attacks lead when assisted by heat, and oxidates and dissolves a portion of it; but its action is feeble and limited. It combines readily with the white oxide of lead. When poured upon the red oxide, it is converted partly into oxy-muriatic acid by the assistance of heat, while the lead, reduced to the state of white oxide, combines with the remainder of the acid||. Thus we see that muriatic acid combines usually with white oxide of lead, and that it is incapable of combining with the red oxide of that metal; but the

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\* Rouelle.

† Bergman, ii. 470.

|| Fabroni.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

§ Van Mons, *Ann. de Chim.* xxvii. 81.



experiments of Proust and Vauquelin have proved that it is capable of combining also with the brown oxide, and forming an oxy-muriat of lead.

1. *Muriat of lead.* This salt may be formed readily by pouring muriatic acid or an alkaline muriat into a solution of nitrat of lead. The muriat precipitates in the state of a white powder. It has a sweetish taste. Its specific gravity is 1.8226\*. It is soluble in 22 parts of cold water, and this solubility is increased considerably by the presence of an acid†. It is soluble in acetous acid; a property by which it may be readily distinguished from sulphat of lead. When its solution in boiling water is allowed to cool, the salt crystallizes in very small six-sided prisms of a white colour, and brilliant appearance like satin. These crystals are not altered by exposure to the air. When heated they melt readily, and when cold assume the appearance of a semitransparent, greyish-white mass, formerly distinguished by the name of *plumbum corneum*. When exposed to a strong heat, they partly evaporate in a visible white smoke, and there remains behind a submuriat of lead; a substance which seems to have been first examined by Bergman†.

This salt, according to Klaproth, is composed of about . . . . . 13.5 acid . . . . .

86.5 oxide

100.0§

Composition.

\* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Chenevix, Nicholson's *Jour.* iv. 223.

‡ Bergman, ii. 470. and iii. 325.

§ Beitrage, ii. 275.

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According to Kirwan, the crystals are composed of

18.23 acid

81.77 oxide

---

100.00

And the salt, when dried, of 17 acid

83 oxide

---

100\*

Formation.

According to this calculation, we may consider 100 parts of the crystallized salt as containing 76 parts of lead in the metallic state.

2. *Oxy-muriat of lead.* When the red oxide of lead is put into a Woulfe's bottle with water, and oxy-muriatic acid gas is made to pass through it, the gas is absorbed, while the oxide acquires a brown colour, and is gradually dissolved. For this curious experiment we are indebted to Mr Proust. In this case the lead absorbs oxygen from the acid, and from a portion of the red oxide also, which is converted into white oxide, and combines with the muriatic acid as it is developed; while the brown oxide, thus formed, combines with new oxy-muriatic acid, and is thus dissolved. The properties of this super-oxygenated salt have not been examined. It is not even known whether it can be crystallized. Its crystals, if they could be formed, would certainly be curious, as they would contain a much greater proportion of oxygen than any other metallic salt whatever. The solution does not crystallize spontaneously; and when evaporated, the acid is apt to fly off, and the brown oxide to be precipitated.

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\* Kirwan On Mineral Waters, Table iv.

*Sp. 5. Phosphat of Lead.*

PHOSPHORIC ACID has but little action on lead ; however, when allowed to remain long in contact with it, the metal is partly oxidated and converted into an insoluble phosphat. The phosphat of lead may be easily formed by mixing the alkaline phosphats with nitrat of lead. The salt immediately precipitates in the state of an insoluble powder.

The salt is found native in different parts of the world. Its colour is then usually green or yellow, and it is often crystallized in six-sided prisms. It is insoluble in water unless there be a considerable excess of acid ; but it is soluble in pure soda, and probably forms with it a triple salt \*. When heated it melts, and assumes on cooling a regular polyhedral form. In a red heat it is decomposed by charcoal, which absorbs the oxygen from both of its component parts. The sulphuric, nitric, and muriatic acids, decompose it by abstracting its base while cold ; but these decompositions do not take place in a strong heat.

The yellow phosphat of lead, from Leadhills in Scotland, is composed, according to my analysis (abstracting the impurities with which it is usually mixed) of

18 acid

82 white oxide

100

Composition.

*Sp. 6. Fluat of Lead.*

FLUORIC ACID has no action on lead ; but it dissolves

\* Vauquelin, *Jour. de Min.* No. 9. p. 6.

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a small proportion of the white oxide of that metal when there is an excess of acid. But the fluat of lead, formed by saturating the acid, is an insoluble powder, which melts easily before the blow-pipe, and lets go its acid. The acid is driven off also by sulphuric acid \*.

*Sp. 7. Borat of Lead.*

BORACIC ACID has no action on lead ; but borat of lead is precipitated in the state of white powder when borat of soda is mixed with nitrat of lead. When one part of boracic acid is melted with two parts of red oxide of lead, the product, according to Reuss, is a greenish-yellow, transparent, hard, insoluble glass †.

*Sp. 8. Carbonat of Lead.*

CARBONIC ACID has no action on lead ; but it combines readily with its oxide. Carbonat of lead is most easily obtained by precipitating lead from its solution in nitric acid by the alkaline carbonats. By that process it is obtained in the state of a white powder.

This salt occurs native in abundance. In that state it is usually white, and has a good deal of lustre. Its specific gravity is 7.2357 †. It is sometimes crystallized in six-sided prisms, terminated by six-sided pyramids, and sometimes in regular octahedrons §. It is insoluble in water. When exposed to the action of the blow-pipe upon charcoal, the lead is immediately reduced to the metallic state.

---

\* Scheele, i. 33. † Reuss *de Sale Sedative*.

‡ Bournon, Nicholson's *Journal*, iv. 220.

§ Haüy, *Jour. de. Min. An.* v. p. 502.



Carbonat of lead, according to the experiments of Bergman, is composed of 16 acid

84 white oxide

---

100 \*

This result nearly coincides with the experiments of Chenevix, who found carbonat of lead to be composed

of ..... 15 acid

85 oxide

---

100 †

According to Bergman, 132 parts of carbonat of lead contain 100 parts of metallic lead.

*Sp. 9. Arseniat of Lead.*

ARSENIC ACID attacks lead in a digesting heat, communicates a portion of its oxygen, and converts it into arseniat of lead in the state of an insoluble white powder. When arsenic acid is poured into the solution of lead in nitric, muriatic, or acetous acids, arseniat of lead precipitates in powder. When this salt is heated it melts; and if charcoal be thrown into the mass while in fusion, arsenic is volatilized, and the lead is reduced; the charcoal abstracting the oxygen from both of the component parts of the salt.

Arseniat of lead is completely insoluble in water. It has been found native. According to the analysis of Chenevix, it is composed of 33 acid

63 white oxide

4 water

---

100 †

Chap. III.

Composi-  
tion.

Composi-  
tion.

\* Bergman, ii. 393.

† Nicholson's *Journal*, iv. 221.

‡ *Phil. Trans.* 1801, p. 199.

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Sp. 10. *Molybdat of Lead.*

THE action of molybdic acid on lead has not been tried; but Scheele ascertained, that when dropt into the solution of lead in nitric or muriatic acid, molybdat of lead was immediately precipitated\*. This salt occurs native in Carinthia. Its composition was first detected by Klaproth.

It has a yellow colour, and is completely insoluble in water. Its specific gravity is 5.706†. Its crystals are cubic or rhomboidal plates. When heated, it decrepitates and melts into a yellowish mass. It is soluble in fixed alkalies and in nitric acid. Muriatic acid decomposes it by the assistance of heat, and carries off the lead. According to the analysis of Klaproth, it is composed of about . . . 34.7 acid

65.3 oxide

100.0 †

Sp. 11. *Chromat of Lead.*

THIS salt may be formed by mixing together the solutions of nitrat of lead and an alkaline chromat. The chromat of lead, in that case, precipitates in the state of a red powder; but it exists native, and is indeed the compound from which chromic acid is usually obtained.

Its colour is red with a shade of yellow; and its crystals are four-sided prisms, sometimes terminated by four-sided pyramids. Its specific gravity is about 6.

\* Scheele, i. 246. † Hatchett, *Phil. Trans.* 1796.

† Beitrage, ii. 275.

It is insoluble in water, but soluble in the fixed alkalies without decomposition. Nitric acid also dissolves it; but muriatic and sulphuric acids decompose it, precipitating the lead in the state of muriat or sulphat. According to the analysis of Vauquelin, it is composed of about . . . . . 34.9 acid

65.1 oxide

---

100.0 \*

*Sp. 12. Acetite of Lead*

ACETOUS ACID, as Vauquelin has shewn, does not attack lead in close vessels; but it occasions its oxidation when the lead is in contact both with the acid and the air, and the oxide is dissolved as it forms. The acetite of lead which is produced by this solution has been long known. It is mentioned by Isaac Hollandus and Raymond Lully. It received formerly a great variety of names; such as, *sugar of lead*, *sugar of Saturn*, *salt of Saturn*, *vinegar of Saturn*, *extract of Saturn*, &c. The solution of lead in acetous acid was strenuously recommended by Goulard, a surgeon of Montpellier, as an excellent application in cases of inflammation. Hence it is often called *Goulard's extract*.

This salt is employed in considerable quantities by dyers and calico printers. They mix it with alum or with sulphat of iron, and by that means compose acetite of alumina or of iron, according to the process; salts which answer much better as mordants for fixing their colours than alum or green vitriol. It is prepared in considerable quantities both in this country and in

Formation.

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\* *Four. de Min.* No. xxxiv. p. 760.

Book II.  
Division II.

Holland and France. The manufacturers distil their own acid in England and Holland from sour beer, and in France from sour wine. The different processes followed by manufacturers have been described by Weber and Machy, and more lately by Pontier \*.

These processes may be reduced to two; either lead in the metallic state is exposed to the action of the acetous acid, or the oxides of lead are dissolved in it. In the first case, thin plates of lead are put into earthen vessels along with acetous acid. The portion of the lead near the surface, as soon as it is covered with a coat of oxide, is removed to the bottom of the vessel, and new plates are brought to the surface. These are incrustated in their turn, and removed to the bottom, where the oxide is dissolved. This change of place is continued daily till the acid has dissolved a sufficient quantity of lead. It is then filtered, and sufficiently concentrated by evaporation. As it cools, the acetite of lead precipitates in small crystals.

Other manufacturers dissolve the white oxide of lead, prepared by exposing the metal to the fumes of vinegar; or they make use of litharge in its stead, and the solution is evaporated in the usual way till the salt crystallizes. This process is considered as more expensive than the other: But might not native carbonat of lead, which is found abundantly in many places, be employed with advantage instead of these artificial oxides?

Properties.

Acetite of lead is usually in the form of small needle-shaped crystals, which have a glossy appearance like satin, and are flat four-sided prisms, terminated by dihedral summits. Its taste is sweet and somewhat astrin-

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\* *Ann. de Chim.* xxxvii. 268.



gent. Its specific gravity is 2.345\*. It is but sparingly soluble in water, unless there be an excess of acid. When exposed to the air it becomes yellow, but undergoes no farther change. Heat decomposes it. When distilled, there comes over an acid liquor, which is the acetous considerably altered; and the residuum, according to Proust, often takes fire spontaneously when exposed to the air. This salt is decomposed by all those acids and their compounds, which form with lead a salt nearly insoluble in water; as the sulphuric, phosphoric, muriatic, fluoric, oxalic, malic, &c.

*Sp. 13. Oxalat of Lead.*

OXALIC ACID blackens lead, but it is scarcely capable of dissolving it; but it dissolves its white oxide, and when nearly saturated deposits small crystalline grains of oxalat of lead. The same crystals are precipitated when oxalic acid is dropt into the nitrat, muriat, or acetite of lead dissolved in water. They are insoluble in alcohol, and scarcely soluble in water, unless they contain an excess of acid. They are composed, according to Bergman's analysis, of about

$$\begin{array}{r}
 41.2 \text{ acid} \\
 58.8 \text{ oxide} \\
 \hline
 100.0 \dagger
 \end{array}$$

*Sp. 14. Tartrite of Lead.*

TARTAROUS ACID has no action on lead; but it combines with its oxide, and precipitates tartrite of lead in the state of an insoluble white powder, from the nitrat,

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\* Hassenfratz, *Ann. de Chim.* xxviii. 12. † Bergman, i. 267.

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Division II.

muriat, and acetite of that metal. According to the analysis of Thenart, it is composed of

34 acid

66 white oxide

---

100\*.

*Sp. 15. Tartrite of Potass-and-lead.*

THIS triple salt may be formed by boiling tartar and oxide of lead together in water. Thenart informs us that it is insoluble, and that it is neither decomposed by alkalies nor by sulphats †.

*Sp. 16. Malat of Lead.*

MALIC ACID does not attack lead; but when poured into a solution of lead in nitric or acetous acid, malat of lead is immediately precipitated ‡; and likewise, as Vauquelin has observed, when acetite of lead is poured into a solution containing malat of lime. This precipitate is easily distinguished by the form of fine light flakes which it has, and by the facility with which it is dissolved by the acetous and weak nitric acids §.

*Sp. 17. Lactat of Lead.*

LACTIC ACID, when digested upon lead for several days, dissolves it. The solution has a sweet and astringent taste, and does not crystallize ||.

*Sp. 18. Mucite of Lead.*

WHEN mucous acid is dropt into the solution of lead

\* *Ann. de Chim.* xxxviii. 37.

† *Ibid.* p. 36.

‡ Scheele, *Crell's Annals*, ii. 7. Engl. Transl.

§ *Ann. de Chim.* xxxv. 155.

|| Scheele, ii. 66.

in muriatic or nitric acids, a white insoluble precipitate is produced \*. Chap. III.

*Sp. 19. Benzoat of Lead.*

BENZOIC ACID dissolves lead with difficulty. The solution yields by evaporation crystals of benzoat of lead of a brilliant white colour, soluble in alcohol and water; not altered by exposure to the air, but decomposed by heat, which drives off their acid. The sulphuric and muriatic acids separate the lead †.

*Sp. 20. Succinat of Lead.*

SUCCINIC ACID scarcely attacks lead, but it dissolves its white oxide; and the solution, according to Wenzel, yields long slender foliated crystals ‡.

*Sp. 21. Sebat of Lead.*

SEBACIC ACID oxidates lead, and dissolves a good deal of its oxide. It precipitates lead from its solution in nitric and acetous acids in the form of white needle-shaped crystals, soluble in water and in acetous acid §.

## GENUS IX. SALTS OF NICKEL.

THE scarcity of nickel, and the difficulty of obtaining it in a state of purity, have hitherto prevented the possibility of an accurate examination of the combinations which its oxide forms with acids. The salts of nickel, therefore, are at present but very imperfectly

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\* Schéele, ii. 86. † Trommsdorf, *Ann. de Chim.* xi. 316.

‡ Wenzel's *Verwand.* p. 322. § Crell, *Phil. Trans.* 1782.

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Division II.

Characters.

known. They may be distinguished by the following properties:

1. Its salts are in general soluble in water, and the solution has a beautiful green colour.
2. Triple prussiat of potass, when dropt into these solutions, occasions a precipitate of a dull green colour.
3. The hydrosulphuret of potass occasions a black precipitate.
4. Sulphurated hydrogen gas, according to Proust, occasions no precipitate.
5. Gallic acid, and the infusion of nutgalls, occasion a greyish white precipitate.
6. Iron, zinc, tin, manganese, or cobalt, when plunged into these solutions, occasion a precipitate of nickel in the metallic state.

*Sp. 1. Sulphat of Nickel.*

SULPHURIC ACID attacks nickel by the assistance of heat. When distilled over it to dryness, there remains behind a green mass soluble in water, and yielding by evaporation crystals of sulphat of nickel. This acid dissolves the oxide of nickel with facility, and yields by evaporation the same salt. The sulphat of nickel has a fine green colour, and crystallizes in decahedrons composed of two four-sided pyramids applied base to base, and truncated at their apexes\*. Fourcroy informs us that he has seen this salt, prepared by Leblanc, crystallized in large four-sided rectangular prisms.

*Sp. 2. Nitrat of Nickel.*

NITRIC ACID dissolves nickel or its oxide when as-

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\* Bergman, ii. 268.



sisted by heat. The solution has a bluish-green colour, and yields by evaporation nitrat of nickel in the form of rhomboidal crystals, which, on exposure to the air, at first deliquesce, but afterwards fall to powder, and gradually lose their acid, so that only the oxide of nickel remains behind\*.

*Sp. 3. Muriat of Nickel.*

MURIATIC ACID dissolves nickel and its oxide slowly, and the assistance of heat is necessary. The solution, which has a green colour, yields when evaporated irregular crystals of muriat of nickel, which are decomposed by heat and by long exposure to the air, though at first they deliquesce like nitrat of nickel†.

*Sp. 4. Phosphat of Nickel.*

PHOSPHORIC ACID is capable of dissolving only a very small portion of the oxide of nickel. The solution does not yield crystals, and has scarcely even a green colour‡. Hence it would seem that the phosphat of nickel is nearly insoluble.

*Sp. 5. Fluat of Nickel.*

FLUORIC ACID dissolves nickel with difficulty, and the solution yields light green-coloured crystals§.

*Sp. 6. and 7. Borat and Carbonat.*

BORACIC ACID can only be combined with nickel by mixing an alkaline borat with a solution of nickel in some acid.

It does not appear from the experiments of Berg-

\* Bergman, ii. 268.

† Ibid.

‡ Ibid.

§ Ibid.

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Division II.

man that carbonic acid is capable of combining with nickel directly; but when 100 parts of nickel are thrown down from their solution in acids by an alkaline carbonat, they weigh 135; whereas they weigh only 128 when thrown down by a pure alkali\*. Hence we may conclude that the carbonat of nickel is composed of about . . . . . 95 oxide

5 acid

---

100

*Sp. 8. Arseniat of Nickel.*

WHEN arsenic acid is digested on nickel, the metal is partly oxidated, and the arseniat of nickel separates in the form of a greenish powder scarcely soluble in water. Nickel is not precipitated from its solution in acids by arsenic acid; but when the alkaline arseniats are employed, arseniat of nickel falls in the state of a greenish-white powder†.

*Sp. 9. Acetite of Nickel.*

ACETOUS ACID dissolves nickel, and forms with its oxide rhomboidal crystals of a very green colour‡.

*Sp. 10. Oxalat of Nickel.*

OXALIC ACID attacks nickel at a digesting heat, and a greenish-white powder is deposited, which is the oxalat of that metal. The same salt is precipitated when oxalic acid is dropt into the solution of nickel in sulphuric, nitric, or muriatic acids. It is scarcely soluble

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\* Bergman, ii. 392.

† Scheele, i. 187.

‡ Bergman, ii. 268.

in water, and is composed, according to Bergman, of Chap. III.  
two parts of acid to one of metal\*.

*Sp. II. Tartrite of Nickel.*

TARTAROUS ACID does not attack nickel†. The compound which it forms with its oxide has not been examined. Neither are we acquainted with any of the remaining species of the salts of nickel.

GENUS X. SALTS OF ZINC.

ALMOST all the acids act with energy on zinc, in consequence of the strong affinity which it has for oxygen. The salts of zinc, therefore, are very easily formed, and, as there is only one oxide of that metal, they are not liable to change their state, like the salts of iron and tin. They may be distinguished by the following properties:

1. The greater number of them are soluble in water, Characters.  
and the solution is colourless and transparent.
2. Triple prussiat of potass occasions a white precipitate when dropt into these solutions.
3. Hydrosulphuret of potass and sulphurated hydrogen gas occasion a white precipitate.
4. Gallic acid and the infusion of nutgalls occasion no precipitate when dropt into these solutions.
5. Alkalies occasion a white precipitate, which is readily dissolved by sulphuric or muriatic acid.
6. It is not precipitated in the metallic form by any of the other metals, unless manganese be an exception.

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\* Bergman, i. 269. † Ibid.

Book II.  
Division II.

*Sp. I. Sulphat of Zinc.*

CONCENTRATED sulphuric acid scarcely acts upon zinc without the assistance of heat; but if it be sufficiently diluted with water, it attacks the metal with force; hydrogen gas is emitted, and the zinc is very speedily dissolved. In this case the water is decomposed; its oxygen combines with the metal, while its hydrogen is exhaled. When the solution is sufficiently concentrated by evaporation, it yields the sulphat of zinc in crystals.

History.

This salt, according to the best accounts, was discovered at Rammelsberg in Germany about the middle of the 16th century. Many ascribe the invention to Julius Duke of Brunswick. Henkel and Newmann were the first chemists who proved that it contained zinc; and Brandt first ascertained its composition completely\*. It is generally formed for commercial purposes from sulphurated oxide of zinc, or blende as it is called by mineralogists. This ore is roasted, which converts the sulphur into an acid; it is then dissolved in water, and concentrated so much that, on cooling, it crystallizes very rapidly, and forms a mass not unlike loaf-sugar. This salt is usually called *white vitriol*. It is almost always contaminated with iron. Hence the yellow spots which are visible on it, and hence also the reason that its solution in water lets fall a dirty brown sediment; a circumstance very much complained of by surgeons when they use that solution in medicine. It may be easily purified by dissolving it in water, and putting into the solution a quantity of zinc.

Purification.

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\* Beckmann's *History of Inventions*, art. *Zinc*.



filings; taking care to agitate it occasionally. The zinc precipitates all the iron, and takes its place. The solution is then to be filtered, and the sulphat of zinc may be obtained from it in crystals by proper evaporation.

This salt when crystallized is transparent and colourless. Its crystals are four-sided flat prisms, terminated by quadrangular pyramids. Two opposite edges of the prism are commonly replaced by small faces, which renders the prism six-sided\*. Its specific gravity when crystallized is 1.912, when in the state in which it commonly occurs in commerce, it is 1.3275 †.

Properties.

At the temperature of 60°, it is soluble in 2.28 parts of water; but it is much more soluble in boiling water ‡. When exposed to the air, it effloresces. When heated, it melts and speedily loses its water of crystallization, and, in a very high temperature, loses part of its acid.

According to the calculation of Bergman, this salt is composed of

40 acid  
20 oxide  
40 water

Composi-  
tion.

---

100 §

According to Kirwan, it is composed of 20.5 acid  
40.0 oxide  
39.5 water

---

100.0 ||

According to the same philosopher, 100 parts of the crystallized salt contain 30 parts of metallic zinc.

\* Bergman, ii. 327. † Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Bergman ii. 328. § Ibid.

|| Kirwan's *Mineral Waters*, Table iv.

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Division II.

*Sp. 2. Sulphite of Zinc.*

Two varieties of sulphited zinc.

HITHERTO the combinations which the sulphurous acid forms with metallic oxides have been examined only by Berthollet and Fourcroy and Vauquelin. To these chemists we are indebted for the discovery that the greater number of metallic sulphites are capable of combining with a quantity of sulphur, and of forming a *sulphurated sulphite*. This is the case in a remarkable degree with the sulphite of zinc.

1. *Sulphurated sulphite*. Sulphurous acid attacks zinc with considerable violence, heat is produced, and sulphurated hydrogen gas is exhaled. The solution has an acrid, astringent, sulphureous taste. When exposed to the air, it becomes thick like honey, and deposits long slender crystals in the form of four-sided prisms, terminated by four-sided pyramids. These are crystals of *sulphurated sulphite of zinc*, as Fourcroy and Vauquelin have proved. They are soluble in water and in alcohol. When exposed to the air, they become white, and deposit a white insoluble powder. Before the blow-pipe the salt swells, emits a brilliant light, and forms dendritical ramifications. When distilled, it yields water, sulphurous acid, sulphuric acid, and sulphur; and there remain behind oxide of zinc and a little sulphat of that metal. Sulphuric, nitric, and muriatic acids, when poured into its solution in water, drive off the sulphurous acid, while a quantity of sulphur precipitates. The theory of the formation of this salt is obvious. During the solution of the zinc, both water and sulphurous acid were decomposed; the oxygen of both combined with the metal; the hydrogen escaped combined with a portion of the sulphur of the decomposed acid, and the rest of the sulphur combined with the sulphite as it formed.

2. *Sulphite of zinc.* Sulphurous acid dissolves the oxide of zinc with the evolution of heat, but without effervescence. The solution yields crystals of sulphite of zinc. These crystals have a less acrid, but more styptic taste than sulphurated sulphite. They are less soluble in water, and more easily crystallized. They are insoluble in alcohol. When exposed to the air, they are very soon changed into sulphat of zinc; whereas the sulphurated sulphite remains long unchanged.

When a mixture of sulphur and white oxide of zinc is treated with sulphurous acid, the product is a sulphurated sulphite\*.

*Sp. 3. Nitrat of Zinc.*

NITRIC ACID attacks zinc with prodigious violence, and has been known even to inflame it. It is necessary to moderate its action by using it in a diluted state: even then considerable heat is evolved, and a strong effervescence is occasioned by the escape of nitrous gas.

The solution is caustic, and yields by evaporation flat striated tetrahedral prisms, terminated by four-sided pyramids. The specific gravity of these crystals is 2.096†. They attract moisture when exposed to the air. When heated, they melt and detonate on burning coals, emitting a red flame. When distilled, they emit red vapours of nitrous acid, and assume a gelatinous form. In a strong heat, they are decomposed completely, giving out nitrous gas and oxygen gas‡.

*Sp. 4. Muriat of Zinc.*

MURIATIC ACID dissolves zinc rapidly and with

\* Fourcroy, v. 380.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Fourcroy, v. 382.

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Division II.

effervescence, owing to the emission of hydrogen gas. The solution is colourless; and when evaporated, does not crystallize, but assumes the form of a jelly. When distilled, a little of its acid separates, and muriat of zinc remains behind in a solid mass, easily fusible. It was formerly known by the name of *butter of zinc*. When heated, it sublimes, and is obtained in a mass of a fine white colour, composed of small needles. Its specific gravity is 1.577 \*. It is very soluble in water, and when exposed to the air, gradually attracts moisture, and assumes a gelatinous consistence. Sulphuric acid decomposes it, and the alkalies precipitate the whole oxide of zinc from its solution †.

*Sp. 5. Phosphat of Zinc.*

PHOSPHORIC ACID attacks zinc with effervescence, and a white powder is gradually deposited, which is the *phosphat of zinc*. The salt may be formed also by pouring an alkaline phosphat into the solutions of sulphat, nitrat, or muriat of zinc. Its properties have not been examined, but it appears to be nearly insoluble in water.

*Sp. 6. Fluat of Zinc.*

FLUORIC ACID attacks zinc with violence, hydrogen gas is emitted, and the metal is oxidated and dissolved. The properties of the fluat thus formed have not been examined ‡.

*Sp. 7. Borat of Zinc.*

BORACIC ACID scarcely attacks zinc; but it com-

\* Hassenfratz, *Ann. de Chim.* xxviii. 13.

† Fourcroy, v. 383.

‡ Scheele, i. 35.



bines with its oxide, and forms with it an insoluble *borat of zinc*. This salt may be precipitated by pouring borat of soda into the nitrat or muriat of zinc.

*Sp. 8. Carbonat of Zinc.*

LIQUID CARBONIC ACID, confined in a vessel with zinc or its oxide reduced to the state of a fine powder, dissolves a considerable portion of it; and the solution, when exposed to the air, is gradually covered with an iridescent pellicle of oxide of zinc \*. The carbonat of zinc may be obtained in the state of a white powder, by precipitating zinc from its solution in acids by means of an alkaline carbonat. According to the analysis of Bergman, native carbonat of zinc is composed of

28 acid

66 oxide

6 water

---

100 †

*Sp. 9. Arseniat of Zinc.*

WHEN arsenic acid is poured upon zinc, an effervescence ensues, arsenical hydrogen gas is emitted, and a black powder precipitates, which is arsenic in the metallic state. Hence we see that the zinc deprives both a portion of water and of arsenic acid of their oxygen. When one part of zinc-filings and two parts of dry arsenic acid are distilled in a retort, a violent detonation takes place when the retort becomes red, occasioned by the sudden absorption of the oxygen of the acid by the zinc. The arseniat of zinc may be precipitated by

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\* Bergman i: 35. † Opusc. ii. 326.

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pouring arsenic acid into the acetite of zinc, or by mixing the solution of the alkaline arseniats with the sulphat of zinc. It is a white powder, insoluble in water\*.

*Sp. 10, 11, and 12.*

By the same process may the tungstat, molybdat, and chromat of zinc be obtained. They also are insoluble in water: the first two are white, the last of an orange-red colour.

*Sp. 13. Acetite of Zinc.*

ACETOUS ACID readily dissolves zinc, and yields by evaporation crystals of acetite of zinc, which were first mentioned by Glauber. This salt has a bitter metallic taste. Its crystals are rhomboidal or hexagonal plates, of a talky appearance. It is not altered by exposure to the air; it is soluble in water. When thrown upon live coals, it burns with a blue flame. When distilled, it yields water, an inflammable liquid, and some oil, and towards the end of the process oxide of zinc sublimes†.

*Sp. 14. Oxalat of Zinc.*

OXALIC ACID attacks zinc with a violent effervescence, and a white powder soon subsides, which is oxalat of zinc. The same salt is precipitated when oxalic acid is dropt into the solution of sulphat, nitrat, or muriat of zinc. This salt is scarcely soluble in water, unless there be an excess of acid‡.

*Sp. 15. Tartrite of Zinc.*

TARTAROUS ACID attacks zinc with effervescence,

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\* Scheele, i. 181. † *Encycl. Method. Chim.* i. 23. ‡ Bergm. i. 271.

and forms with it a salt difficultly soluble in water, the properties of which have not been examined \*.

Chap. III.

*Sp. 16. Tartrate of Potass-and-zinc.*

THIS salt may be formed by boiling together tartar and zinc filings in water. It is very soluble in water, and not easily crystallized. No precipitation is produced in its solution by the alkalies or their carbonats †.

*Sp. 17. Citrat of Zinc.*

CITRIC ACID attacks zinc with effervescence, and gradually deposits small brilliant crystals of citrat of zinc. They are insoluble in water, and have a styptic and metallic taste. They are composed of

50 acid  
50 oxide

---

100 ‡

*Sp. 18. Malat of Zinc.*

MALIC ACID dissolves zinc, and yields by evaporation beautiful crystals of malat of zinc §.

*Sp. 19. Lactat of Zinc.*

LACTIC ACID dissolves zinc with effervescence, and the salt formed is capable of crystallizing ||.

*Sp. 20. Benzoat of Zinc.*

ZINC is readily dissolved by benzoic acid. The so-

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\* Dijon Academicians,

† Dijon Academicians; and Thenart, *Ann. de Chim.* xxxviii. 35.

‡ Vauquelin, *Foureroy*, vii. 209.

§ Scheele, *Crell's Annals*, ii. 10. Engl. Transl.

|| Scheele, ii. 65.

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lution yields crystals which are soluble in water and alcohol. When exposed to heat, their acid is volatilized \*.

*Sp. 21. Succinat of Zinc.*

SUCCINIC ACID dissolves zinc with effervescence; and the solution yields long slender foliated crystals, the properties of which have not been examined †.

*Sp. 22. Sebat of Zinc.*

SEBACIC ACID dissolves zinc with great facility; but the resulting salt has not been examined ‡.

GENUS XI. SALTS OF BISMUTH.

THE salts of bismuth have not been examined with much attention by chemists; indeed bismuth and its combinations have been hitherto very much neglected. These salts may be distinguished by the following properties:

Characters.

1. The solution of bismuth in acids is usually colourless. When water is poured into it, a white precipitate immediately falls, consisting chiefly of the white oxide of bismuth.

2. Triple prussiat of potass occasions in these solutions a precipitate of a white colour, sometimes with a shade of yellow.

3. Hydrosulphuret of potass and sulphurated hydrogen gas occasion a black precipitate.

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\* Trommsdorf, *Ann. de Chim.* xi. 317.

† Wenzel's *Verwand.* p. 330.

‡ Crell, *Phil. Trans.* 1782.



4. Gallic acid and the infusion of nutgalls occasion an orange-coloured precipitate.

5. When a plate of copper or tin is put into the solution of bismuth, this last metal is often precipitated in the metallic state.

*Sp. 1. Sulphat of Bismuth.*

SULPHURIC ACID has no action on bismuth while cold; but by the assistance of heat it converts that metal into a white oxide, while at the same time sulphurous acid is exhaled, and even sulphur sublimed, if the heat be considerable. When the saline mass, thus formed, is washed with water, almost the whole of the acid is separated, carrying along with it a very small portion of the oxide; and this lixivium yields, by evaporation, small crystals in needles, which are decomposed, and their base precipitated when any attempt is made to dissolve them in water.

*Sp. 2. Sulphite of Bismuth.*

SULPHUROUS ACID does not attack bismuth; but it combines with its oxide, and forms with it a salt insoluble in water even when assisted by an excess of acid. It has a sulphureous taste; and before the blow-pipe melts into a reddish yellow mass, which is soon reduced upon charcoal. When distilled, the acid is driven off, and the whole oxide remains in a state of purity\*.

*Sp. 3. Nitrat of Bismuth.*

NITRIC ACID, when concentrated, attacks bismuth

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\* Fourcroy, v. 204.

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with great violence, a vast quantity of nitrous gas is emitted, the metal is converted into a white oxide, much heat is evolved, and sometimes even sparks of fire are darted out of the mixture. When the acid is diluted, the action is less violent, and the oxide of bismuth is dissolved as it forms. The solution is colourless; and on cooling lets fall crystals of a white colour, and generally attached to each other in the form of stars. They are small four-sided prisms, generally terminated by four-sided summits.

Properties.

This salt, when exposed to the air, attracts a little moisture, and its surface is covered with a crust of white oxide. On burning coals it detonates feebly, emitting red sparks, and leaves a yellowish powder not easily reduced. When triturated with mercury it detonates loudly\*. When put into water it is immediately decomposed; that liquid absorbing its acid and leaving the white oxide of bismuth. Hence the reason that when we write upon paper with a solution of bismuth in nitric acid, the characters, at first invisible, become white when the paper is plunged into water, as Brugnatelli first observed †.

When the solution of bismuth in nitric acid is diluted with water, the greatest part of the metal separates in the state of a white oxide. In this state it was formerly known by the name of *magistery of bismuth*, and in commerce it is distinguished by the appellation of *pearl white*. To obtain it of a fine white colour, it is necessary to employ a great proportion of water, and to wash the precipitate well.

\* Brugnatelli, *Ann. de Chim.* xxvii. 73.

† Ibid. iii. 296

*Sp. 4. Muriat of Bismuth.*

MURIATIC ACID has scarcely any action on bismuth while cold; but when distilled off that metal, previously reduced to powder, it gradually oxidates, and brings it to the state of a white powder. Muriat of bismuth may be readily formed by dissolving the metal in nitro-muriatic acid, or in oxy-muriatic acid. When the solution is evaporated, it is said to yield small prismatic crystals. The muriat of bismuth, when evaporated to dryness, sublimes by the application of a moderate heat, and forms a thick concrete mass, readily melting when heated, formerly known by the name of *butter of bismuth*. It was prepared also by distilling a mixture of two parts of oxy-muriat of mercury and one part of bismuth: an amalgam of bismuth remains in the retort, while the *butter*, as it was called, sublimes\*.

*Sp. 5, 6, 7, 8.*

THE combinations which the oxide of bismuth forms with phosphoric, fluoric, boracic, and carbonic acids, have not hitherto been examined with accuracy. They may be formed by pouring into the solution of bismuth in nitric acid the alkaline phosphats, fluats, borats, or carbonats. The salts required precipitate in the state of a white powder.

*Sp. 9. Arseniat of Bismuth.*

ARSENIC ACID oxidates bismuth by a digesting heat; and the metal is covered with a white powder, which is

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\* Poli, *Mem. Par.* 1713.

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arseniat of bismuth. Part also of the arseniat remains in solution, but the oxide is precipitated by the addition of water. The arseniat of bismuth precipitates when arsenic acid is poured into the nitrat of bismuth. The white powder thus obtained is difficultly fusible; but when heated with charcoal, arsenic sublimes, and the bismuth is reduced\*.

*Sp. 10. Acetite of Bismuth.*

ACETOUS ACID has but little action on bismuth; but the acetite of bismuth may be obtained by mixing together the solutions of nitrat of bismuth and acetite of potass. When the mixture is heated, it redissolves the precipitate which had at first formed, and at the same time yields a number of thin talky crystals resembling boracic acid. Morveau, to whom we are indebted for this experiment, has ascertained also, that the addition of acetous acid deprives nitrat of bismuth of the property of affording a precipitate when diluted with water†.

*Sp. 11. Oxalat of Bismuth.*

OXALIC ACID scarcely attacks bismuth; but it combines with its oxide, and forms with it an oxalat in the state of a white powder, scarcely soluble in water. When oxalic acid is dropt into nitrat of bismuth, small transparent polygonous grains are gradually precipitated, which possess the same properties as the white powder, and do not become opaque when put into water‡.

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\* Scheele, i. 184.

† *Encyc. Method. Chim.* i. 10.

‡ Bergman, i. 269.



*Sp. 12. Tartrate of Bismuth.*

TARTAROUS ACID does not attack bismuth; but when dropt into the solution of that metal in nitrous acid, tartrate of bismuth precipitates in the state of a white powder insoluble in water.

*Sp. 13. Benzoate of Bismuth.*

BENZOIC ACID dissolves the oxide of bismuth with facility; and the solution yields white needle-shaped crystals, which are not altered by exposure to the air, are soluble in water, and very sparingly soluble in alcohol. Sulphuric and muriatic acids decompose this salt, and heat volatilizes its acid \*.

The remaining salts of bismuth are unknown.

## GENUS XII. SALTS OF ANTIMONY.

THE various doses of oxygen with which antimony is capable of combining, render it probable that the salts of antimony are numerous; but hitherto scarcely any of them have been examined. Chemists have confined themselves to the combination of the acidulous oxide of antimony with acids; an oxide which possesses a number of properties which assimilate it to the acids, and which seems scarcely susceptible of forming permanent compounds with acids. Antimonial salts may be distinguished by the following properties:

1. Their solutions are usually colourless, and in most cases a white precipitate falls when they are diluted with water. Characters.

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\* Trommsdorf, *Ann. de Chim.* xi. 317 .

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2. Triple prussiat of potass occasions a white precipitate when drop'd into these solutions. This precipitate is merely the oxide of the metal precipitated by the water of the prussiat. When applied sufficiently concentrated, or in crystals, no precipitation takes place. In this property antimony agrees with platinum\*.

3. Hydrosulphuret of potass occasions an orange-coloured precipitate.

4. Gallic acid and the infusion of nutgalls occasion a white precipitate, which is merely the oxide of the metal separated by the water of the infusion.

5. When a plate of iron or zinc is plunged into antimonial solutions, a black powder precipitates in great abundance, and very speedily when there is an excess of acid, and the solution is not too much concentrated.

#### *Sp. 1. Sulphat of Antimony.*

SULPHURIC ACID has no action on antimony while cold; but at the boiling temperature it oxidates that metal with effervescence, sulphurous acid is exhaled, and even sulphur sublimed, and there remains in the retort a soft white mass, evidently composed of the acidulous oxide and sulphurous acid. Water carries off the acid and a small portion of the oxide, but leaves the greater part in the state of a white powder. When the solution is evaporated, the remainder of the oxide precipitates, so that the salt cannot be obtained in a crystalline form. The white powder may be considered as a subsulphat of antimony, for it still retains a portion of acid.

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\* Klaproth, *Crell's Annals*, 1798, i. 99.

*Sp. 2. Sulphite of Antimony.*

SULPHUROUS ACID has no action on antimony while cold, but when hot it changes it into an oxide. The sulphite of antimony is precipitated in the state of an insoluble white powder when sulphurous acid is poured into the solution of antimony in muriatic acid. It has an acrid and astringent taste, melts when heated, and is volatilized and decomposed. When distilled in close vessels, it yields sulphurous acid; and there remains a reddish brown mass, consisting probably of hydrosulphuret of antimony\*.

*Sp. 3. Nitrat of Antimony.*

NITRIC ACID attacks antimony with great violence. Both the acid and water are decomposed, abundance of nitrous gas is emitted, and a considerable portion of ammonia is formed and combines with the acid while the metal is converted into an insoluble white oxide. It does not appear that any combination takes place between this acid and the acidulous oxide of antimony, the oxide which is formed by this process; and no attempt has hitherto been made to combine it with any of the other oxides of antimony. Probably it does not combine even with them, in consequence of the facility with which it converts them into the acidulous oxide.

*Sp. 4. Muriat of Antimony.*

MURIATIC ACID has no effect upon antimony at first; but the metal is gradually dissolved when it is kept long in contact with that acid. The solution is

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\* Fourcroy, v. 231.

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yellow, and yields by evaporation small needle-form crystals, consisting no doubt of *uriat* of antimony, or of muriatic acid combined with antimony, oxidated to a minimum.

Muriatic acid dissolves the white oxide of antimony with facility; but it is nitro-muriatic acid which is considered as by far the best solvent of that metal. These solutions may be considered as containing an *oxy-uriat* of antimony, or muriatic acid combined with antimony oxidated to a maximum. That salt was formerly known by the name of *butter of antimony*. It was usually prepared by triturating together one part of antimony and two parts of oxy-uriat of mercury, and then distilling them in a retort. At a moderate temperature the oxy-uriat of antimony passes over. It is in the state of a thick fatty mass, of a greyish white colour, and often crystallized in four-sided prisms. It is exceedingly caustic, becomes coloured when exposed to the air, and melts at a very moderate temperature. When diluted with water, it is partly decomposed, and the greater part separates in the form of a white oxide. In this state it was formerly known by the name of *powder of Algoroth*.

#### *Sp. 5. Phosphat of Antimony.*

THE action of phosphoric acid on antimony has never been examined. Neither is the salt better known which that acid may be supposed capable of forming with the oxides of that metal.

#### *Sp. 6. Phosphat of Lime-and-antimony.*

THE well-known medicine called *James's powder* has been shewn by the analysis of Dr Pearson to be a compound of phosphoric acid, lime, and oxide of antimo-



ny; we may therefore consider it as a triple salt. It is usually in the form of a white powder, nearly insoluble in water, but partially soluble in acids. The energy with which it acts as an emetic is well known. From Dr Pearson's analysis it appears to be composed of about . . . . 43 phosphat of lime  
 . . . . . 57 oxide of antimony

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100

It may be composed by calcining in a white heat a mixture of equal parts of sulphuret of antimony and the ashes of bones\*.

*Sp. 7, 8, 9, 10, 11.*

THE fluat, borat, carbonat, tungstat, and chromat of antimony are still unknown, no accurate experiments having been made to ascertain even the mode of forming these salts.

*Sp. 12. Arseniat of Antimony.*

WHEN arsenic acid and antimony are digested together, a white powder separates, consisting of arseniat of antimony. This powder is soluble in muriatic acid, and precipitated again by the affusion of water. The alkaline arseniats precipitate the same salt from the solution of antimony in muriatic, tartarous, or acetous acids. When a mixture of one part of antimony and three parts of arsenic acid are distilled in a retort, it enters into fusion, and then takes fire; arsenic is sublimed together with a red mass, and sulphurous acid is exhaled†.

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\*\* *Phil. Trans.* 1791, p. 317.

† Scheele, i. 184.

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*Sp. 13. Acetite of Antimony.*

ACETOUS ACID has little or no action on antimony ; but it dissolves a small portion of its oxide, as Morveau has shewn, and the solution, according to Wenzel, yields small crystals. This salt is soluble in water, and was employed by Angelus Sala and some subsequent physicians as an emetic\*.

*Sp. 14. Oxalat of Antimony.*

OXALIC ACID scarcely attacks antimony ; but it dissolves a small portion of its oxide. The solution yields by evaporation small crystalline grains difficultly soluble in water. The same salt is precipitated by adding oxalic acid to the solution of antimony in acetous or sulphuric acid ; but oxalic acid occasions no precipitate in the oxy-muriat of antimony†.

*Sp. 15. Tartrite of Antimony.*

TARTAROUS ACID has no action on antimony, but it dissolves a small portion of its oxides. The solution scarcely crystallizes ; but easily assumes the form of a jelly‡.

*Sp. 16. Tartite of Potass-and-Antimony.*

History.

THIS salt, usually denominated *tartar emetic*, is much more employed in this country as a medicine than all the other antimonial preparations put together. It was first made known by Adrian de Mynsicht in his *Thesaurus Medico-chymicus*, published in 1631. But the preparation was in all probability suggested by a treatise,

\* *Encyc. Method. Chim.* i. 6.

† Bergman, i. 271.

‡ *Ibid.* 370.

intituled *Methodus in Pulverem*, published in Italy in 1620. This book, written by Dr Cornachinus, gives an account of the method of preparing a powder which had been invented by Dudley Earl of Warwick, and which had acquired great celebrity in Italy in consequence of the wonderful cures which it had performed. This powder was composed of scammony, sulphuret of antimony, and tartar, trituated together. The extraordinary effects which it produced would naturally draw the attention of chemists to the combination of antimonial preparations with tartar.

Tartar emetic was first prepared by boiling together tartar and the *crocus metallorum* \*, as it was called, in water, filtering the solution, and evaporating it till it yields crystals: glass of antimony was afterwards substituted for the crocus. But it would be needless to enumerate the numerous methods which have been adopted according to the fancy of different operators. These methods have been collected by Bergman, and are described by him in his treatise on *Antimoniated Tartar* †.

Preparation.

At present the glass of antimony, or the acidulous oxide of antimony, are usually employed. Either of these is mixed with its own weight of tartar, and the mixture boiled in ten or twelve parts of water, till the tartar be saturated. The solution is then filtered and evaporated till a pellicle forms on its surface. On cooling it deposits regular crystals of tartar emetic.

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\* An impure hydrosulphuret, formed by detonating in a crucible equal weights of sulphuret of antimony and nitre, and washing the residuum in water till the liquid comes off tasteless,

† *Opusc.* i. 338.

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Thenart has observed, that there always remains in the solution a quantity of uncombined tartrite of potass; it ought not therefore to be evaporated too far, otherwise the crystals of that salt will mix with those of the tartar emetic\*.

Properties.

TARTAR EMETIC is of a white colour, and crystallizes in regular tetrahedrons. When exposed to the air, it gradually loses its transparency and effloresces. It is soluble in 80 parts of cold water, and in about 40 parts of boiling water. Heat decomposes it by destroying the acid, while the potass and oxide of antimony remain behind. It is decomposed by the alkaline earths, by the alkalies and their carbonats, and by the hydrosulphurets, and several of the metals. It is decomposed also by the decoctions of plants, particularly those that are astringent and bitter, as Peruvian bark, &c. Consequently it never ought to be given in conjunction with any of these bodies.

Composition.

From the analysis of Thenart, it appears that this salt is composed of . . . 35.4 tartarous acid

39.6 oxide

16.7 potass

8.3 water

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100.0

Or of . . . . . 56.3 tartrite of antimony

35.4 tartrite of potass

8.3 water

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100.0 †

\* *Ann. de Chim.* xxxviii. 39.

† *Ibid.*



*Sp. 17. Benzoat of Antimony.*

BENZOIC ACID readily dissolves the oxide of antimony, and the solution yields crystals, which remain dry when exposed to the air, and are decomposed by heat\*.

*Sp. 18. Sebat of Antimony.*

SEBACIC ACID dissolves the oxide of antimony by the assistance of heat, and forms a salt in small crystals, which do not deliquesce in the air†.

## GENUS XIII. SALTS OF TELLURIUM.

TELLURIUM has been known for so short a time as a distinct métal, and the quantity of it hitherto examined has been so small, that the salts which it forms with acids cannot be supposed to be much known. Only the following facts have been ascertained.

The salts of tellurium may be distinguished by the following properties:

1. Alkalies, when dropt into their solution, occasion a white precipitate, which disappears again if the alkali be added in excess. Characters.
2. Triple prussiat of potass occasions no precipitate.
3. Hydrosulphuret of potass occasions a brown or blackish precipitate.
4. The infusion of nutgalls occasions a flaky precipitate of a yellow colour.
5. Zinc, iron, and antimony, when plunged into these solutions, occasion the tellurium to separate in the

\* Trommsdorf, *Ann. de Chim.* xi. 317.

† Crell, *Phil. Trans.* 1782.

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state of a black powder, which resumes its metallic brilliancy when rubbed \*.

*Sp. 1. Sulphat of Tellurium.*

WHEN one part of tellurium is confined with 100 parts of sulphuric acid in a close vessel, it dissolves and gives the acid a crimson colour. When water is dropt into the acid, the red colour disappears, and the metal is precipitated in black flakes. When heated, the colour equally disappears, and the metal precipitates. Diluted sulphuric acid, mixed with a little nitric acid, dissolves a considerable portion of tellurium, the solution is colourless, and no precipitate is produced in it by water †.

*Sp. 2. Nitrat of Tellurium.*

NITRIC ACID dissolves tellurium with facility. The solution is colourless, and yields, when concentrated, small white, light, needle-formed dendritical crystals ‡.

*Sp. 3. Muriat of Tellurium.*

NITRO-MURIATIC ACID dissolves tellurium readily. The solution is transparent; but when diluted with water, it lets fall the oxide of tellurium in the state of a white precipite, soluble in muriatic acid §.

GENUS XIV. SALTS OF ARSENIC.

ARSENIC is capable of assuming the form of an acid, and even its white oxide has several acid properties.

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\* Klaproth, *Crell's Annals*, 1798, i. 98.

† Ibid. p. 98.

‡ Ibid. p. 97.

§ Ibid. p. 98.

Hence it is more disposed to combine with metallic bases than to form salts by uniting with acids. Indeed it has not been proved that the oxide of arsenic is capable of combining with acids, and of forming crystallizable salts. However, as several of the acids have the property of dissolving it, which must be considered as a species of combination, and as the knowledge of the properties of these solutions is sometimes of importance in mineralogical investigations, it will be proper to give an account of them in this place.

The solutions of arsenic may be distinguished by the following properties:

1. Triple prussiat of potass occasions a white precipitate when poured into solutions containing arsenic \*. Characters!
2. Hydrosulphuret of potass produces a yellow precipitate, or at least gives a yellow colour to the solution.
3. Gallic acid and the infusion of nutgalls occasion scarcely any change in the solutions of arsenic.
4. The addition of water occasions a white precipitate of oxide of arsenic †, which, when heated with charcoal, emits a white smoke, having the smell of arsenic.

#### *Sp. I. Sulphat of Arsenic.*

SULPHURIC ACID has no action on arsenic while cold, but when heated, sulphurous acid gas is emitted, and the metal is converted into a white oxide, a small portion only of which is retained in solution. The acid

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\* The solution of arsenic in those acids which convert it into an acid, is not disturbed by the triple prussiat of potass.

† Except when the arsenic is converted into an acid.

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dissolves equally a small quantity of the white oxide of arsenic; but the addition of water precipitates a white powder in the form of crystalline grains. These, according to Bergman, are composed of the white oxide of arsenic, combined with a small portion of acid \*.

*Sp. 2. Nitrat of Arsenic:*

NITRIC ACID attacks arsenic with violence, and converts it into white oxide, while nitrous gas and azotic gas are emitted. An additional dose of acid converts the oxide into arsenic acid. There is therefore no such salt as nitrat of arsenic; the nitric acid does not combine with the white oxide.

*Sp. 3. Muriat of Arsenic.*

MURIATIC ACID has scarcely any action on arsenic while cold; but when heated it dissolves it readily, at the same time a quantity of arsenicated hydrogen gas is emitted. White oxide of arsenic is also dissolved by this acid with facility, especially if a little nitrous acid be mixed with it. At a boiling heat the muriatic acid dissolves about the third part of its weight of white oxide; but it allows the greater part to precipitate again as the solution cools. The addition of water precipitates the greatest part of the remainder; but the muriat of arsenic, according to the experiments of Bergman, may be obtained in the state of crystals. It is very volatile, and but sparingly soluble in water †.

This salt may be formed also by triturating together equal parts of oxy-muriat of mercury and oxide of arsenic, or metallic arsenic, and distilling the mixture

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\* Bergman, ii. 292.

† Ibid. ii. 294.



with a moderate heat. There comes over a transparent liquor of the consistence of oil, part of which congeals in the receiver. This substance is muriat of arsenic. It was described by Lemery and others under the name of *butter of arsenic*, or *corrosive oil of arsenic*.

The action of the other acids on arsenic has scarcely been examined except by Bergman. According to him, phosphoric, fluoric, and arsenic acids dissolve it, and yield crystalline grains scarcely soluble in water: oxalic and tartarous acids dissolve the white oxide readily, and furnish prismatic crystals: acetous acid also dissolves it\*.

#### GENUS XV. SALTS OF COBALT.

THE salts of cobalt have attracted the attention of chemists, in consequence of the property which some of them have of changing their colour when heated, and thus forming what has received the name of *sympathetic ink*: an appellation given to all liquids, the characters formed by which are colourless and invisible when written upon paper, but become visible and coloured by undergoing certain processes: and likewise to those liquids which form characters upon paper susceptible of changing their colour by certain processes. It is probable that chemists have not hitherto had an opportunity of often examining the pure salts of cobalt; for several of the other metals adhere to cobalt with such persevering obstinacy, that it is very difficult to obtain it in a separate state. The salts of cobalt may be distinguished by the following properties:

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\* Bergman, ii. 295.

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Characters.

1. The greater number of them are soluble in water, and the solution has a reddish or brownish colour.
2. The alkalies, when dropt into these solutions, occasion a blue-coloured precipitate.
3. Triple prussiat of potass occasions a brownish yellow precipitate, often with a shade of blue.
4. Hydrosulphuret of potass occasions a black precipitate, soluble again if the hydrosulphuret be added in excess. According to Proust, sulphurated hydrogen gas occasions no precipitate in these solutions\*.
5. Gallic acid produces no change; but the tincture of nutgalls occasions a yellowish-white precipitate.
6. Cobalt is not precipitated from its solution in acids by zinc.

*Sp. 1. Sulphat of Cobalt.*

SULPHURIC ACID oxidates cobalt with the assistance of heat; sulphurous acid gas is emitted, and there remains behind a brownish red mass readily dissolved by water. The solution is red; and yields by evaporation small needle-form crystals, consisting of rhomboidal prisms, terminated by dihedral summits. This salt has a reddish colour. When heated it melts, swells up, and is decomposed, leaving the oxide of cobalt of a deep blue colour. It is decomposed also by alkalies, which precipitate its base in the form of a flesh-coloured powder.

*Sp. 2. Nitrat of Cobalt.*

NITRIC ACID attacks cobalt with violence, especially when assisted by heat. The solution has a red colour,

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\* *Ann. de Chim.* xxxv. 54.

and yields by evaporation small prismatic crystals of a red colour, deliquescent in the air, and decomposed by heat, leaving a deep red powder.

*Sp. 3. Muriat of Cobalt.*

MURIATIC-ACID acts with difficulty upon cobalt, even when assisted by heat; but it dissolves the oxide of that metal with great facility, and even takes it from sulphuric acid. The solution of oxide of cobalt in muriatic acid has a pale red colour, and yields by evaporation small deliquescent crystals of muriat of cobalt.

This solution constitutes the first and best known of all the sympathetic inks. It is diluted with water till its colour almost disappears; and then the characters written with it on paper are invisible while cold, but if the paper be gently heated they acquire a fine green colour, which disappears again when the paper cools. This may be repeated as often as we please, provided care be taken not to heat the paper too much, otherwise the characters acquire a permanent brown colour. Klaproth has shewn, that this change to green only takes place when the cobalt-solution is contaminated with iron: if the cobalt be pure, the characters; instead of a green, acquire a blue colour when heated\*. This sympathetic ink was first made known by Waitz in 1705†; it was described a second time by Teichmeyer in 1731‡; and a third time by Hellot in 1737§. The cause of this singular change of colour has not hitherto been explained in a satisfactory manner. It takes place

Sympathe-  
tic ink.

\* Klaproth's *Observations on the Fossils of Cornwall*, p. 64. Eng. Trans.

† See Wiegleb's *Geschichte*, i. 126.

‡ *Commerc. Litterarum*, p. 91.

§ *Mem. Par.* 1737.

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equally in close vessels; so that it can scarcely be ascribed to the action of the air or of moisture. At present it is supposed, but without any direct proof, to be owing to the partial deoxidation of the oxide of cobalt by heat, and its reabsorption of oxygen when cold.

Sp. 4, 5, 6, 7, 8, 9.

**Phosphat.** PHOSPHORIC ACID dissolves cobalt, and forms a reddish-coloured solution which deposits phosphat of cobalt when saturated.

**Fluat.** FLUORIC ACID does not attack cobalt, but it dissolves its oxide, and forms with it a yellow-coloured gelatinous solution\*.

**Borat.** BORACIC ACID has no action on cobalt; but the borat of cobalt may be formed by mixing borat of soda with nitrat of cobalt.

**Carbonat.** CARBONAT OF COBALT may be formed also by precipitating cobalt from its solution in acids by means of an alkaline carbonat.

The *tungstat*, *molybdat*, and *chromat* of cobalt are still unknown.

Sp. 10. *Arseniat of Cobalt.*

ARSENIC ACID, when digested upon cobalt, acquires a red colour, but it does not dissolve the metal completely. Arsenic acid does not precipitate cobalt from its solution in acids; but the alkaline arseniats occasion a precipitate of a fine red colour, which is arseniat of cobalt†. This salt is found native; sometimes in the state of a fine red efflorescence, and sometimes crystallized in small four-sided prisms or tables.

\* Scheele, i. 35.

† Ibid. 186.



*Sp. 11. Acetite of Cobalt.*

ACETOUS ACID dissolves the oxide of cobalt with facility. The solution does not crystallize; and when evaporated to dryness, soon deliquesces again. It has a fine red colour while cold, but becomes blue when heated\*.

*Sp. 12. Oxalat of Cobalt.*

OXALIC ACID attacks cobalt, and converts it into a red powder, which is oxalat of cobalt. This salt is insoluble in water, but it dissolves in an excess of acid, and yields crystals. Oxalic acid precipitates an oxalat of cobalt from the solution of that metal in most acids†.

The remaining salts of cobalt have not hitherto been examined.

## GENUS XVI. SALTS OF MANGANESE.

ALL the properties of this genus of salts with which we are even at present acquainted were ascertained by Bergman and Scheele, by whose labours the oxide of manganese, one of the most important of all their instruments, was first put into the hands of chemists. The salts of manganese may be distinguished by the following properties:

1. They are almost all soluble in water; and the solution, when treated with fixed alkalies, deposits a white or reddish coloured precipitate, which very soon becomes black when exposed to the air. Characters,

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\* Wenzel's *Verwand.* p. 194.

† Bergman, i. 279.

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2. Triple prussiat of potass occasions a yellowish-white precipitate when dropt into these solutions.

3. Hydrosulphuret of potass occasions a white precipitate. Sulphurated hydrogen gas gives the solution a whiter colour, but produces no precipitate.

4. Gallic acid occasions no precipitate.

5. Manganese is not precipitated from its solution in the metallic state by any of the other metals.

*Sp. I. Sulphated Manganese.*

SULPHURIC ACID acts with energy on manganese, especially when diluted with two or three times its weight of water, and forms with it a colourless solution. It dissolves also with equal facility the white and red oxides of manganese; but it has no action whatever on the black oxide unless assisted by heat. When that is the case, oxygen gas passes off in abundance, and the oxide is dissolved. The same solution takes place without the emission of that gas when a little sugar is added to the mixture. Hence we see that the black oxide is incapable of combining with sulphuric acid, since it always loses a portion of its oxygen before solution. But Bergman has shewn, that both the white and the red oxide combine with that acid, and form with it a salt. So that we have two combinations of sulphuric acid and manganese: first, the combination of sulphuric acid and the white oxide, which form *sulphat* of manganese; and, secondly, the combination of the acid with the red oxide, which constitutes *oxy-sulphat* of manganese.

1. *Sulphat of manganese.* This salt is obtained pure by dissolving manganese in diluted sulphuric acid, or by dissolving the black oxide in that acid, adding at the same time a little sugar. The solution is colour-

less, and yields by evaporation transparent rhomboidal crystals of sulphat of manganese. These crystals have a very bitter taste, and are decomposed by heat, which drives off their acid. Alkalies precipitate from them the manganese in the state of a white oxide\*.

2. *Oxy-sulphat of manganese.* This salt may be obtained by distilling sulphuric acid from the black oxide of manganese, and washing the residuum in water. A red or rather violet coloured liquid is thus obtained, which holds in solution the oxy-sulphat of manganese. This solution is difficultly crystallized, but passes readily into a gelatinous form. The few crystals which are mixed with this jelly are soft, and have but little permanency. When evaporated to dryness, it yields thin red-coloured saline crusts, which precipitate successively from the surface, and which do not readily deliquesce. This salt is very soluble in water; and alkalies precipitate the manganese in the state of a red oxide, which soon becomes black when exposed to the air†.

Sulphurous acid readily dissolves the black oxide of manganese, and forms with it sulphat of manganese, as Scheele ascertained‡. The theory of this is obvious. Part of its oxygen is abstracted from the manganese by the acid; in consequence of which, the black oxide is converted into white oxide, and the sulphurous into sulphuric acid. It is not known whether sulphurous acid forms with the oxides of manganese a permanent salt.

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\* Bergman, ii. 210.

† Ibid. p. 215.

‡ Scheele, i. 43.

*Sp. 2. Nitrated Manganese.*

NITRIC ACID dissolves manganese with effervescence, occasioned by the emission of nitrous gas. It dissolves the white oxide with facility, and without the emission of any gas: but it has very little action on the black oxide; however, by very long digestion, it at last dissolves a part of it. The solution goes on much more rapidly if a little sugar or gum, or any similar substance, be added, and at the same time a quantity of carbonic acid gas is emitted. Hence we see that the black oxide must part with a portion of its oxygen before nitric acid can dissolve it. Nitrous acid acts upon the black oxide much more readily, and is converted entirely into nitric acid. The solution, in what manner soever it has been made, is always colourless, provided the manganese be pure. Hence we may conclude that it contains only the white oxide. So that, as far as is known at present, there is no such substance as *oxy-nitrat* of manganese. This solution does not crystallize how slowly so ever it be evaporated. Heat decomposes it, and leaves the oxide\*.

*Sp. 3. Muriated Manganese.*

MURIATIC ACID readily dissolves manganese with an effervescence occasioned by the emission of hydrogen gas. It dissolves the white oxide without effervescence, and the solution is colourless. When allowed to remain cold upon the black oxide, it dissolves a portion of it, and forms a red solution, which deposits red oxide when diluted with water. When heat is applied

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\* Scheele, i. 43, 64; and Bergman, ii. 216.



to the mixture of black oxide of manganese and muriatic acid, an effervescence takes place, and oxy-muriatic acid gas is emitted. The oxide becomes white and gradually dissolves. In this case the acid is divided into two portions; one absorbs oxygen from the metal, and flies off in the state of gas; the other dissolves the white oxide, as it is set at liberty by the decomposition of the black oxide. If sugar or any other similar vegetable substance is added, no oxy-muriatic acid gas is emitted, but instead of it carbonic acid gas. From these facts it is obvious that muriatic acid combines both with the white and red oxides of manganese; so that there is both a *muriat* and *oxy-muriat* of that metal. But the properties of these salts are still almost unknown. According to Bergman, the *muriat* crystallizes with difficulty, and when evaporated to dryness yields a saline mass, which attracts moisture. The solution of the *oxy-muriat* is red, and it seems to be partly decomposed by water\*.

*Sp. 4. Phosphat of Manganese.*

PHOSPHORIC ACID has but little action on manganese or its oxides, because it forms with them a salt difficultly soluble in water. But phosphat of manganese may be obtained in the form of a precipitate, by mixing an alkaline phosphat with the solution of manganese in any of the three mineral acids†. This salt has not been hitherto examined.

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\* Bergman, ii. 217.—Scheele, i. 46. and 67.

† Scheele, i. 48.—Bergman, ii. 219.

*Sp. 5. and 6. Fluat and Borat of Manganese.*

THE fluoric and boracic acids form likewise with the oxides of manganese salts difficultly soluble in water, the properties of which have not hitherto been much examined. These acids have but little action on manganese and its oxides; but the fluat or borat of manganese may be easily formed by pouring the alkaline fluats or borats into sulphat or muriat of manganese.

*Sp. 7. Carbonat of Manganese.*

LIQUID CARBONIC ACID attacks manganese or its black oxide, and dissolves a small portion. When the solution is exposed to the air, the acid gradually escapes, and a white pellicle forms on its surface, consisting of white oxide. During the solution of manganese in this acid, an odour similar to that of burning fat is perceptible \*.

*Remaining Species.*

Acetite. 8. ACETOUS ACID has but little effect upon manganese immediately; but it dissolves a small portion by long digestion, as it does also of the black oxide. The solution does not yield crystals, and when evaporated to dryness soon deliquesces again †.

Oxalat. 9. Oxalic acid attacks manganese, and dissolves the black oxide with effervescence. The solution, when saturated, lets fall the oxalat of manganese in the state of a white powder. Oxalic acid precipitates the same powder from the solution of manganese in sulphuric, nitric, or muriatic acid ‡.

\* Bergman, i. 35; and Scheele, i. 51

† Bergman, ii. 219.

‡ Ibid. i. 272, and ii. 219.

10. Tartarous acid dissolves black oxide of manganese cold; but the solution is blackish: when heated, an effervescence ensues, owing to the decomposition of part of the acid and the escape of carbonic acid gas, and the solution becomes colourless. Tartrite of potass precipitates tartrite of manganese from the solution of that metal in any of the three mineral acids \*. Chap. III.  
Tartrite.

11. Citric acid acts upon the black oxide of manganese exactly as tartarous acid †. Citrat.

12. Arsenic acid dissolves the white oxide of manganese with facility; and when it approaches the point of saturation, the solution becomes thick, with small crystals, which separate. These crystals are arseniat of manganese. They are precipitated when an alkaline arseniat is dropt into the solution of manganese in an acid. These crystals do not melt when heated, neither does arsenic sublime, unless charcoal be mixed with them ‡. Arseniat.

13. Benzoic acid dissolves the white oxide of arsenic with facility. The solution yields small crystalline scales easily soluble in water, but sparingly in alcohol. They are not altered by exposure to the air §. Benzoat.

## GENUS XVII. SALTS OF TUNGSTEN.

THIS genus of salts is altogether unknown; the scarcity of tungsten, and the difficulty of obtaining it in a state of purity, having hitherto prevented the possibility of attempting to ascertain the compounds which its oxides are capable of forming with acids.

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\* Bergman, ii. 219.

† Ibid. p. 220.

‡ Scheele, i. 188.

§ Trommsdorf, *Ann. de Chim.* xi. 317.

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Neither sulphuric nor muriatic acids seem capable of altering the metal ; but nitro-muriatic acid attacks it at a boiling heat, and nitrous gas is emitted \*.

### GENUS XVIII. SALTS OF MOLYBDENUM.

THIS genus is scarcely better known than the preceding, and for the same reasons. It has only been ascertained that muriatic acid does not attack molybdenum ; that sulphuric acid oxidates it at a boiling heat ; and that nitric acid converts it into molybdic acid.

### GENUS XIX. SALTS OF URANIUM.

THIS genus of salts has been hitherto examined only by Klaproth and Richter. The salts of uranium may be distinguished by the following properties :

Characters.

1. The greater number of them are soluble in water, and the solution has a yellow colour.
2. The pure alkalis occasion in these solutions a yellow precipitate ; the alkaline carbonats a white precipitate, soluble in an excess of alkali.
3. Triple prussiat of potass occasions a brownish-red precipitate, which does not assume the form of flakes like the prussiat of copper.
4. Hydrosulphuret of potass occasions a brownish-yellow precipitate.
5. The infusion of nutgalls occasions a chocolate-coloured precipitate.
6. No precipitate is occasioned by zinc, iron, or tin†.

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\* Vauquelin and Hecht, *Jour. de Min.* No. xix. p. 25.

† Klaproth, *Crell's Annals*, i. 130. Engl. Transl.



*Sp. 1.* Sulphuric acid, when diluted, readily dissolves the yellow oxide of uranium, and the solution yields by evaporation fine orange-coloured prisms of sulphat of uranium \*. Chap. III.  
Sulphat.

2. Nitric acid dissolves the oxide of uranium with facility, and the solution yields, when evaporated, large crystals of nitrat of uranium of a beautiful yellowish-green colour, and in the form of hexagonal tables; which effloresce in the air †. Nitrat.

3. Muriatic acid forms with oxide of uranium deliquescent crystals of a yellowish-green colour, and in the form of four-sided tables ‡. Muriat.

4. Phosphoric acid forms with oxide of uranium yellowish-white flakes, scarcely soluble in water. The salt may be precipitated by adding phosphoric acid to the acetite of uranium §. Phosphat.

5. Fluoric acid dissolves the yellow oxide, and forms with it crystals which do not deliquesce. Fluat.

6. When an alkaline arseniat is dropt into nitrat of uranium, the arseniat of uranium precipitates in the state of a yellowish-white powder. Arseniat.

7. and 8. The tungstat and molybdat of uranium may be obtained by a similar process. The first is a brownish-white powder, insoluble in water; the second is whitish-yellow, and difficultly soluble.

9. Concentrated acetous acid dissolves oxide of uranium by digestion, and yields beautiful yellow crystals in the form of long, slender, transparent, four-sided prisms, terminated by four-sided pyramids. When heated gradually, the acid is decomposed and driven off, Acetite.

\* Klaproth, *Crell's Annals*, i. 130. Engl. Trans. † Ibid.

‡ Klaproth, *ibid.* p. 135.

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but the remaining oxide still retains the form of the crystals\*.

Tartrite.

10. Tartarous acid forms with the oxide of uranium a salt scarcely soluble in water.

Richter formed also the borat, oxalat, citrat, malat, benzoat, succinat, and sebat of uranium; but the properties of these salts have not been described.

## GENUS XX. SALTS OF TITANIUM.

FOR all that is at present known respecting this genus of salts, we are indebted to the experiments of Gregor, Klaproth, Vauquelin and Hecht. The salts of titanium may be distinguished by the following properties:

Characters.

1. They are in general colourless, and in some degree soluble in water.

2. The alkaline carbonats occasion in these solutions a white flaky precipitate.

3. Triple prussiat of potass occasions a grass-green precipitate mixed with brown. When an alkali is dropt in after the prussiat, the precipitate becomes purple, then blue, and at last white.

4. Hydrosulphuret of potass occasions a dirty glass-green precipitate. Sulphurated hydrogen gas occasions no precipitate.

5. The infusion of nutgalls occasions a very bulky reddish-brown precipitate. If the solution is concentrated, it assumes the appearance of curdled blood.

6. When a rod of tin is plunged into a solution of titanium, the liquid around it gradually assumes a fine

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\* Klaproth, *Crell's Annals*, i. 135, Engl. Trans.

red colour. A rod of zinc, on the other hand, occasions a deep blue colour \*.

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*Sp. 1.* Boiling sulphuric acid oxidates titanium, and dissolves a small portion of it; but on the red oxide of titanium that acid has no action whatever. It dissolves the carbonat of that metal with effervescence, occasioned by the emission of carbonic acid. The solution, when evaporated, is converted into a white opaque gelatinous mass.

Sulphat.

2. Nitric acid has no action on the red oxide of titanium, and scarcely any upon the metal; but it dissolves the carbonat, provided heat be applied; and the solution yields by evaporation transparent crystals, in the form of elongated rhombs, having two opposite angles truncated, so as to represent six-sided tables. According to Vauquelin and Hecht, this solution only succeeds when the metal is combined with a minimum of oxygen.

Nitrat.

3. Muriatic acid dissolves titanium; but it has no effect upon its red oxide. The carbonat of titanium is readily dissolved by this acid; and the solution, according to Klaproth, yields transparent cubic crystals. According to Vauquelin and Hecht, the solution is yellow, and assumes the form of a jelly when evaporated. Heat occasions the emission of oxy-muriatic acid, and the oxide precipitates, and is no longer soluble in muriatic acid, unless it be boiled in nitric acid. Hence they conclude, that the muriat contains titanium combined with a maximum of oxygen, and that the suboxide is incapable of uniting with muriatic acid.

Muriat.

4 and 5. When the phosphoric or arsenic acid is

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\* Klaproth's *Beitrage*, i. 233.

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Carbonat,

dropt into the solution of titanium in acids, it occasions a white precipitate.

6. When one part of red oxide of titanium and six parts of carbonat of potass are melted together in a crucible, the mass, when washed sufficiently with water, leaves a white powder, with a slight red tinge, which Vauquelin and Hecht have ascertained to be carbonat of titanium. According to the experiments of these chemists, it is composed of

75 white oxide  
25 carbonic acid

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100

7 and 8. Oxalic and tartarous acids likewise occasion a white precipitate, but it is redissolved again almost as soon as formed \*.

### GENUS XXI. SALTS OF CHROMUM.

THIS genus of salts is still altogether unknown; the small quantity of chromum hitherto obtained not having permitted chemists to examine the combinations which its oxides are susceptible of forming with acids. But the presence of this metal in solution may be ascertained by the following properties:

Characters.

1. Triple prussiat of potass occasions a green precipitate.
2. The infusion of nutgalls occasions a brown precipitate.
3. The hydrosulphuret of potass occasions a green precipitate, which a few drops of nitric acid change to yellow.

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\* *Jour. de. Min.* No. xv. p. 1.



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SECT. III.

## REMARKS ON THE SALTS.

SUCH are the properties of all the salts which have been hitherto examined by chemists, and which amount to no fewer than 505. Great as this number is, it cannot be doubted that the class of salts will be considerably increased hereafter.

Of these bodies, there are some, as alum, copperas, &c. which constitute the basis of different arts and manufactures, and which therefore are of sufficient importance to deserve an accurate examination even on their own account. Others, again, are the source from which chemists obtain many of the most valuable of their instruments of analysis; as nitre, common salt, phosphat of lime, sal ammoniac, sulphat of barytes, &c.; and therefore naturally claim the particular attention of all those who cultivate the science. But it must be allowed, that by far the greater number of saline bodies are at present of no apparent use whatever, either in the arts or in chemistry. At first sight it may appear a very useless piece of labour to be at the trouble of examining and describing these; but there are several reasons which render a precise knowledge of all the salts not only proper, but even necessary.

Importance  
of the salts.

Were we to limit ourselves to the examination of those things whose usefulness is already known, there would be an end of all improvement. Every thing must be useless, as far as regards us, till its properties

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be known, and the purposes to which it may be applied ascertained. Many of those salts which we at present consider as of no utility, may hereafter be found of the greatest consequence, when their properties have been more completely investigated. This remark has been verified more than once within these few years. The muriat of lime, for instance, was formerly thrown away, but is now applied with great advantage to produce artificial cold; and the oxy-muriats, though a new class of salts, constitute an essential ingredient in the process of bleaching. Want of utility therefore is but a meagre reason for neglecting the examination of the salts, unless it could be demonstrated *a priori* that they never can be applied to any use.

But were we even certain that this were the case, still the examination of a great number of these salts would be indispensable: For those salts which are the most useful are seldom or never found in a state of purity; they are constantly mixed and contaminated with other salts, from which it is necessary to free them before they will answer the purposes to which they are usually applied. Now these foreign salts cannot be separated unless we be acquainted with them, at least sufficiently to know the effect of different agents upon them; that is, unless we be acquainted with their properties. Thus we see that it is not possible to obtain those salts which are really useful, without at the same time knowing the nature of many salts which have been applied to no use. Thus common salt is always mixed with muriat of magnesia, and cannot be obtained unless we understand the method of separating or decomposing that salt.

But it is not strictly true that many of the salts are

altogether useless. It may be affirmed, with the greatest truth, that, even at present, there is not one among them, the knowledge of whose properties is not of some advantage. One of the most important and difficult things in chemistry is to ascertain exactly the nature and composition of different bodies. Now this can only be done by observing the changes produced upon them by other bodies, and the compounds which they are capable of forming. Thus if, on examining a substance, I find, that when, combined with sulphuric acid, it forms a heavy insoluble white powder; with muriatic acid, a very soluble salt, which crystallizes in tables, and is insoluble in alcohol; with phosphoric and oxalic acid likewise an insoluble powder, &c.—I conclude, without hesitation, that it is barytes. A substance which dissolves in sulphuric acid, and forms a salt of a blue colour, crystallized in rhomboidal prisms, of an acrid taste and caustic, which forms with muriatic acid a green salt, which becomes blue when mixed with ammonia, and which when mixed with alkalies occasions a blue or green precipitate—I conclude to be copper. Thus it is the knowledge of the salts which the different alkalies, earths, metals, and acids, are capable of forming, which enables us to discover their presence when they enter as ingredients into different compounds. Here, then, is a reason for studying the properties of the salts, independent of their utility as individual bodies; and it may be affirmed with truth, that chemical skill is in every case proportional to the extent of this knowledge.

The great number of saline bodies renders it a difficult task to remember the properties of each. Indeed the thing would be impossible, were it not the salts na-

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turally arrange themselves into certain groups, the individuals belonging to which all agree in certain general properties which may be remembered with facility; and after these general properties have indicated the group to which a given salt belongs, it is much easier to ascertain the species.

Salts divided into  
two orders.

The salts may be divided conveniently into two orders, under one or other of which every salt is to be placed. These two orders constitute the two first Sections of this Chapter. The first order comprehends under it all the earthy and alkaline salts; the second order all the metalline salts.

First order.

The first order may be distinguished by the following characters: The salts belonging to this order are, either, 1. Soluble in water; and in that case the solution is not precipitated by hydrosulphuret of potass\*, triple prussiat of potass†, or infusion of nutgalls‡: or, 2. Insoluble in water; and in that case they are either soluble in muriatic acid, or become so when heated to redness, or fused with carbonat of potass; and the solution yields a precipitate when sulphuric acid is added, or if not, at least when potass is added. The insoluble salts afford with borax, before the blow-pipe, a white glass or enamel.

Second order.

The second order may be distinguished by the following properties: The salts belonging to it are, either, 1. Soluble in water; in which case they afford a precipitate with hydrosulphuret of potass, triple prussiat

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\* Except salts with base of alumina or zirconia.

† Except salts with base of yttria or zirconia.

‡ Except salts with base of yttria, glucina, or zirconia.



of potass\*, and the infusion of nutgalls†: or, 2. Insoluble in water; in which case, when fused with borax by the blow-pipe upon charcoal, they either afford a button of metal, or form with the borax a coloured glass.

The first order is divisible into 32 genera; the salts belonging to which may be distinguished by the characters of these genera given in the first Section of this Chapter. The species may be ascertained by the description there given; but the investigation will be much facilitated by attending to the following observations:

1. The species may be distinguished into two kinds; those whose base is an *alkali*, and those which have an *earthy* base. Characters of the species.

2. The alkaline salts are all soluble in water. Potass occasions no precipitate of a white powder when added to the solution; neither does oxalic acid occasion any precipitate.

3. The salts with an ammoniacal base are all either dissipated entirely, or converted into an acid when exposed to a red heat.

4. Many of the earthy salts are insoluble in water; a white powder is precipitated from the soluble salts either by the addition of potass or of sulphuric acid.

5. The salts whose base is barytes are all‡ insoluble in water, or nearly so, except six; namely, the nitrat, muriat, acetite, lactat, benzoat, and prussiat; from the

\* Except salts of gold, platinum, antimony, and tellurium.

† Except salts of platinum, zinc, arsenic, and manganese.

‡ Five of them are still unknown; namely, the oxy-muriat, molybdat, chromat, gallat, and sebat.

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solutions of these, sulphuric acid occasions a white heavy insoluble precipitate.

6. All salts whose base is strontian are nearly insoluble in water, as far as they have been examined, except six; namely, nitrat, muriat, oxy-muriat, acetite, tartrite, and citrat. These also yield an insoluble white powder with sulphuric acid. But the alkalies occasion no precipitate either in the solutions of barytic or strontian salts.

7. All salts whose base is lime are very sparingly soluble in water except ten; namely, nitrat, muriat, oxy-muriat, arseniat, acetite, malat, lactat, benzoat, prussiat, and sebat. The lime is precipitate from these solutions by oxalic acid, fixed alkalies, and by sulphuric acid, if the solution be concentrated, but not by ammonia.

8. The magnesian salts are all soluble in water except seven; namely, phosphite, fluat, carbonat, oxalat, tartrite, mucite, and camphorat. Their solution yields a precipitate with ammonia, which forms with sulphuric acid a very soluble bitter salt.

9. The alkaline earths form with acids a greater number of salts soluble in water in proportion as the alkaline properties of the earth diminish. Barytes forms salts, the greater number of which are insoluble; strontian seems to form a greater number of soluble salts than barytes; lime forms a still greater number; and almost the whole of the magnesian salts are soluble in water.

10. Six of the aluminous salts are insoluble in water; namely, sulphite, phosphat, borat, arseniat, tungstat, and mucite. The aluminous salts are all deprived of their acid by heat. With potass they yield a precipi-

tate which dissolves in sulphuric acid; and when sulphat of potass is added to the solution, crystals of alum are gradually obtained. The aluminous salts let fall a precipitate when hydrosulphuret of potass is dropt into their solution.

11. The salts of yttria are decomposed by heat and by alkalies; they have a sweetish astringent taste; triple prussiat of potass and infusion of nutgalls occasion a precipitate when poured into their solutions.

12. The salts of glucina are decomposed by heat and by alkalies: they have a sweetish taste. The precipitate separated from them by alkalies, redissolved in nitric or muriatic acid, is again precipitated by the infusion of nutgalls, but not by triple prussiat of potass.

13. The zirconian salts have an austere taste: they are decomposed by heat and by alkalies. The precipitate separated from them by these last bodies, when redissolved in muriatic acid, is precipitated by hydrosulphuret of potass, triple prussiat of potass, and by the infusion of nutgalls.

The second order of salts is divisible into 21 genera, each of which may be recognised by the characters given in the second Section. The species in these genera may be distinguished from each other by the properties of the different acids which form them; and these properties have been enumerated in the first Section as the characteristic marks of the genera of earthy and metallic salts.

The following TABLE, which gives a synoptical view of the properties of the most important salts, will add considerably to the facility of distinguishing the different species.

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Salt.	Taste.	Figure of Crystals.	Action of Air.	Solubility in 100 parts Water at 60°.	Solubility in 100 parts Water at 212°.	Action of Heat.
Sulphat of barytes	None	Rhomboidal prisms	None	0.002	0.	Decrepitates
potass	Bitter	Six-sided prisms	None	6.25	20.	Decrepitates
soda	Bitter	Six-sided prisms	Effloresces	37.	125.	Watery fusion
strontian	None	Rhomboidal prisms	None	0.00	0.02	
lime	Little	Rhomboidal prisms	None	0.2	0.22	Decrepitates
ammonia	Bitter	Six-sided prisms	Subdeliquesces	50.	100.	Decrepitates and melts
magnesia	Bitter	Four-sided prisms	Effloresces	100.	133.	Watery fusion
Alum	Astringent	Octahedrons	Little	5.	133.	Watery fusion
Sulphite of barytes	None	Tetrahedrons	Chang. to sulph.	0.	0.	
lime	None	Six-sided prisms	Effloresces	0.125		Falls to powder
potass	Sulphur.	Rhomboidal plates	Effloresces	100.		Decrepitates
soda	Sulphur.	Four-sided prisms	Effloresces	25.	100.	Watery fusion
ammonia	Sulphur.	Six-sided prisms	Subdeliquesces	100.		Decrepitates
magnesia	Little	Tetrahedrons	Effloresces	5.		Swells
Nitrat of barytes	Acrid	Octahedrons	None	8.	25.	Decrepitates
potass	Cooling	Six-sided prisms	None	14.25	100.	Melts
soda	Cooling	Rhomboidal prisms	Subdeliquesces	33.	100 +	Melts
strontian	Pungent	Octahedrons	Little	100.	200.	Decrepitates and melts
lime	Bitter	Six-sided prisms	Deliquesces	400.	Any quantity	Watery fusion
ammonia	Acrid	Six-sided prisms	Deliquesces	50.	200.	Melts
magnesia	Bitter	Rhomboidal prisms	Deliquesces	100.	100 +	Watery fusion
Muriat of barytes	Astringent	Four-sided prisms	None	20.		Decrepitates
potass	Bitter	Cubes	None	33.		Decrepitates
soda	Salt	Cubes	None	35.42	36.16	Decrepitates
strontian	Sharp	Six-sided prisms	Little	150.	Any quantity	Watery fusion
lime	Bitter	Six-sided prisms	Deliquesces	200.		Watery fusion
ammonia	Acrid	Four-sided pyramids	Subdeliquesces	33.		Sublimes
magnesia	Bitter	Needles	Deliquesces	100.		Watery fusion



Salts.	Taste.	Figure of Crystals.	Action of Air.	Solubility in 100 parts		Action of Heat.
				at 60°	Water at 212°	
Oxy-muriat of potass	Cooling	Rhomboidal plates	None	6.	40.	Gives out oxygen
Phosphat of barytes	None	o	None	o.	o.	Little
strontian	None	o	None	o.	o.	Little
lime	None	Six-sided prisms	None	o.	o.	Little
potass	Salt	A gelatinous mass	Deliquesces	25.	50.	Watery fusion
soda	Salt	Rhomboidal prisms	Effloresces	25.	25 +	Watery fusion
ammonia	Cooling	Four-sided prisms	None	6.6	o.	Falls to a powder
magnesia	Cooling	Six-sided prisms	Effloresces	o.	o.	Decrepitates
Fluat of lime	None	Cubes	None	8.4	16.8	Watery fusion
Borax	Styptic	Six-sided prisms	Subeffloresces	o.	o.	Decrepitates
Carbonat of barytes	None	Various	None	0.023	0.043	Little
strontian	None		None	o.	0.065	Little
lime	None	Rhomboidal prisms	None	o.	o.	Decrepitates
potass	Alkaline	Four-sided prisms	None	25.	83½	Watery fusion
soda	Alkaline	Octahedr truncated	Effloresces	50.	100 +	Watery fusion
magnesia	None	Six-sided prisms	Effloresces	2.	100.	Decrepitates
ammonia	Urinous	Irregular	None	50 +		Evaporates
Acetite of barytes	Bitter	Needles	Subeffloresces	100.		Decomposed
potass	Hot	Plates	Deliquesces	35.		Melts
soda	Sharp	Striated prisms	None		40.8	Melts
strontian	Bitter		None			Decomposed
lime	Cool	Slender prisms	None			Decomposed
ammonia	Sweetish	o	Deliquesces		Very soluble	Melts and sublimes
magnesia	Acid	Irregular prisms	Deliquesces		Very soluble	Decomposed
Tartar	Bitter	Four-sided prisms	None	1½	3½	Melts
Tartrate of potass	Bitter	Eight-sided prisms	None	25.		Melts
Tartrate of potass-and-soda	Bitter		Effloresces	25.		Melts

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## CHAP. IV.

### OF HYDROSULPHURETS.

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Properties  
of sulphu-  
rated hy-  
drogen.

SULPHURATED HYDROGEN GAS possesses the properties of an acid. It is absorbed by water in considerable quantities, and the solution reddens vegetable blues; it combines also with alkalies and earths, and with several metallic oxides. The greater number of these properties were first pointed out with precision by Mr Kirwan; but they were afterwards much more fully developed by Berthollet.

Liquid sulphurated hydrogen, or sulphurated hydrogen gas dissolved in water, is not decomposed by exposure to the air; but the gas is gradually separated and carried off by the air without decomposition. When sulphurous acid is mixed with this solution, both the sulphurated hydrogen and the acid are in a great measure decomposed; the hydrogen of the one combines with the oxygen of the other, and forms water; while the sulphur of both is precipitated, as was first observed by Fourcroy, and more fully ascertained by Berthollet. Nitric acid produces the same effect unless it be too much diluted with water. Hence the reason that sulphur precipitates when that acid is mixed with water, holding sulphurated hydrogen in solution, as Bergman first observed. Oxy-muriatic acid, on the other hand, converts the sulphurated hydrogen into water

and sulphuric acid, by supplying both of its component parts with oxygen.

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Sulphurated hydrogen has a strong action on the greater number of metallic oxides; its hydrogen abstracts oxygen from these bodies, and thus either brings them to the metallic state or to a minimum of oxygen; while at the same time its sulphur combines with the metal thus regenerated. Hence the reason of the change produced upon the solutions of the metallic salts by the infusion of liquid sulphurated hydrogen. All the genera of metallic salts are precipitated by this substance excepting five; namely, those which contain the following metals:

Precipitates metals.

- |            |                       |
|------------|-----------------------|
| 1. Iron,   | 4. Manganese,         |
| 2. Nickel, | 5. Titanium: and also |
| 3. Cobalt, | 6. Molybdenum*.       |

Berthollet and Proust have shewn, that the oxides of these metals are reduced by sulphurated hydrogen to a minimum of oxygen; but as in that state they have but little affinity for sulphur, they continue combined with the acids which held them at first in solution. Tin, on the other hand, which at a minimum of oxidation has a strong affinity for sulphur, is precipitated, though sulphurated hydrogen only reduces it to a minimum of oxidation.

Nature of the precipitates.

The metallic solutions differ considerably in the facility with which they afford precipitates with sulphurated hydrogen; and Mr Proust has shewn that, with a little address, metals may, in many cases, be separated from each other by means of this agent. For instance, if copper, lead, zinc, and iron, be held in solu-

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\* When in the state of an acid and combined with an alkali.

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tion together in nitric acid, sulphurated hydrogen first separates the copper in the form of a black precipitate, which may be removed by filtration; next, the lead; and, lastly, the zinc; while the iron still continues in solution\*. The different metals may be distinguished by the colour of the precipitate which their solutions yield with sulphurated hydrogen. The colours of these different precipitates may be seen in the following

TABLE:

Gold . . . . .	Yellow
Silver . . . . .	Black
Mercury . . . . .	Black
Copper . . . . .	Black
Tin . . . . .	Brown
Lead . . . . .	Black
Zinc . . . . .	Yellow
Bismuth . . . . .	Black
Antimony . . . . .	Orange
Arsenic . . . . .	Yellow
Molybdenum . . . . .	Brown

Super-sulphurated hydrogen.

Sulphurated hydrogen has the property of combining with sulphur, and of forming a compound which has the appearance of a yellow oil. It was first observed by Scheele†; and Berthollet‡, who first examined its nature, has given it the name of *hydrogenated sulphur*. When hydrogenated sulphuret of potass is poured by little and little into muriatic acid, scarcely any sulphurated hydrogen gas is exhaled, but hydrogenated sulphur gradually precipitates to the bottom of the vessel. This substance, when heated, easily allows the sulphu-

\* *Jour. de Phys.* li. 174.

† Scheele on Fire, p. 192. Engl. Trans.

‡ *Ann. de Chim.* xxv. 247.



rated hydrogen gas to exhale, and is converted into sulphur. The same change takes place when it is exposed to the open air.

Thus we see that sulphur and hydrogen are capable of combining in two proportions, or, which is the same thing, that hydrogen combines with two doses of sulphur. The first of these constitutes sulphurated hydrogen gas, or hepatic air; which, according to Thenart, is composed of about

29	hydrogen
71	sulphur

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100

The addition of another dose of sulphur constitutes *hydrogenated sulphur*, which Mr Kirwan has with great propriety denominated *super-sulphurated hydrogen*; a name which certainly ought to be adopted\*. Both of these substances combine with different bases, and constitute very peculiar genera of compounds, which deserve a particular examination on account of the important purposes which they serve in analysis. The combinations which sulphurated hydrogen forms with bases, have been called by Berthollet *hydrosulphurets*, and the compounds formed by super-sulphurated hydrogen, *hydrogenated sulphurets*†.

The alkaline and earthy hydrosulphurets may be formed by dissolving or mixing these bases respectively

Hydrosulphurets,

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\* Kirwan on *Mineral Waters*, p. 11.

† This denomination, as Kirwan has well observed, is very improper, as it does not indicate the composition, and is exceedingly unwieldy. Mr Kirwan uses the term *hepatule* instead of *hydrosulphuret*, and *hepar* for *hydrogenated sulphuret*. *Hepar* would certainly be far preferable, were it not unluckily ambiguous, having been used likewise to denote the sulphurets. However, I shall use it occasionally in Kirwan's sense.

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How formed.

with water, and causing sulphurated hydrogen gas to pass through them till they refuse to absorb any more. The excess of the gas is driven off by heating the solution. It is proper to cause the sulphurated hydrogen gas to pass through a small vessel of water before it reaches the base with which it is to combine, in order to separate any impurities with which it might be mixed. By this method solutions of the different hydrosulphurets in water may be obtained. They are colourless and transparent while kept in close vessels, but when exposed to the air, they soon become coloured. This change is produced by the decomposition of part of their sulphurated hydrogen by the air. Its hydrogen combines with the oxygen of the air, and forms water, while the sulphur is set at liberty, and thus darkens the colour. Hitherto only the alkalies, alkaline earths, and magnesia, have been combined with sulphurated hydrogen. Alumina and zirconia do not combine with it at all: glucina and silica have not been tried.

If these compounds be decomposed while they are colourless, by pouring upon them sulphuric acid, muriatic acid, or any other acid which does not act upon hydrogen, the sulphurated hydrogen gas exhales without the deposition of a single particle of sulphur; but if the hydrosulphuret has become yellow, some sulphur is always deposited during its decomposition, and the quantity of sulphur is proportioned to the deepness of the colour.

The yellow colour, therefore, which hydrosulphurets acquire by exposure to the atmosphere is owing to a commencement of decomposition. Part of the hydrogen of the sulphurated hydrogen abandons the sulphur, combines with the oxygen of the atmosphere, and forms water. By degrees, however, a portion of the

sulphur is also converted into an acid; and when the proportion of sulphurated hydrogen is diminished, and that of the sulphur increased to a certain point, the sulphur and the hydrogen combine equally with oxygen.

If sulphuric or muriatic acids be poured upon a hydrosulphuret after it has been for some time exposed to the air, a quantity of sulphurated hydrogen gas exhales, sulphur is deposited, and after an interval of time sulphurous acid is disengaged. It is therefore sulphurous, and not sulphuric acid, which is formed while the hydrosulphuret spontaneously absorbs oxygen. This acid, however, is not perceptible till after a certain interval of time, when separated from the hydrosulphuret by means of an acid; because as long as it meets with sulphurated hydrogen a reciprocal decomposition takes place. The oxygen of the acid combines with the hydrogen of the gas, and the sulphur of both is precipitated.

These hydrosulphurets have not been sufficiently examined to admit of a detailed description of each. None of them seem capable of crystallizing except the hydrosulphuret of barytes. If a solution of sulphuret of barytes in water, or, more properly, if hydrogenous sulphuret of barytes be evaporated, a great number of confused crystals are formed; if these be separated quickly by filtration, and placed upon blotting paper to dry, a white crystalline substance is obtained, which is hydrosulphuret of barytes.

Properties.

The affinities of the alkalies and earths for sulphurated hydrogen appear from the experiments of Berthollet to be as follows:

Barytes,

Potass,

Affinities.

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Soda,

Lime,

Ammonia,

Magnesia,

Zirconia.

The hydrogenated sulphurets or hepars of alkalies and earths may be formed by boiling the base together with sulphur in a quantity of pure water, or by dissolving their sulphurets in water; in either case, super-sulphurated hydrogen is formed, which combines with the base. These compounds were known formerly by the name of *liquid hepars* or *livers of sulphur*. They may be formed also, as Berthollet has shown, by pouring a liquid hydrosulphuret upon sulphur; a portion of the sulphur is dissolved without the assistance of heat, the liquid becomes dark-coloured, and is converted into hydrogenated sulphuret \*. When prepared by the first process, they contain an excess of sulphur, which separates when sulphurated hydrogen is made to pass through them.

Precipitate  
metals.

The hydrosulphurets and hydrogenated sulphurets have the property of precipitating all metallic bodies from any solution in which they may be contained. They are therefore very valuable tests of the presence of metals, as they do not precipitate any of the earths except alumina and zirconia. The metallic precipitates are occasioned by the combination of sulphurated hydrogen, or of sulphur with the metallic body, which is always deprived of a portion or of the whole of its oxygen, while at the same time the base of the hydrosulphuret combines with the acid which held the oxide in solution. The precipitate of alumina and zirconia

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\* *Ann. de Chim.* xxv. 242.



is occasioned by the base of the hydrosulphuret, while the sulphurated hydrogen is exhaled in the state of gas, not being susceptible of combining with these earths. Hydrosulphuret or hydrogenated sulphuret of potass is usually made choice of for these precipitations, and the peculiar metal precipitated may in many cases be ascertained by the colour of the precipitate. The colour of these different precipitates may be seen by the following TABLE :

Metals	Precipitate by	
	Hydrosulphuret of Potass	Hydrogenated sulphuret of Potass.
Gold . . . . .	Yellow . . . . .	Yellow.
Silver . . . . .	Black . . . . .	Black.
Mercury . . . . .	Brown black . . . . .	Brown, becoming black.
Copper . . . . .	Black . . . . .	Brown.
Iron . . . . .	Black . . . . .	Black, becoming yellow.
Tin . . . . .	Black . . . . .	
Lead . . . . .	Black . . . . .	White, becoming black
Nickel . . . . .	Black . . . . .	
Zinc . . . . .	White . . . . .	White.
Bismuth . . . . .	Black . . . . .	Black.
Antimony . . . . .	Orange . . . . .	Orange-yellow.
Tellurium . . . . .	Black ? . . . . .	Deep brown or black.
Arsenic . . . . .	Yellow . . . . .	Yellow.
Cobalt . . . . .	Black . . . . .	
Manganese . . . . .	White . . . . .	
Uranium . . . . .	Brown . . . . .	Brownish-yellow *.
Titanium . . . . .	Glass-green . . . . .	Bluish-green *.
Chromum . . . . .	Green . . . . .	

The nature of these precipitates has hitherto been very much overlooked by chemists. The subject, however,

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\* In these experiments hepar of ammonia was used by Klaproth.

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Of the pre-  
cipitates.

deserves a very particular examination. The following observations will give a pretty complete view of the present state of our knowledge.

1. Stahl ascertained long ago that sulphuret of potass is capable of oxidating gold when melted with it in a crucible, and that the mixture is soluble in water and has a yellow colour; but the nature of this combination has not hitherto been investigated\*.

2. Lewis has ascertained that platinum is attacked when treated in the same way by sulphuret of potass; but the nature of the combination is still unknown.

3. Silver is capable of combining with sulphurated hydrogen; but the black precipitate occasioned by pouring a hydrosulphuret into a solution of silver, seems to consist chiefly of sulphuret of silver.

4. The same observation applies to mercury; but Berthollet has shewn that the black mercurial sulphuret contains also a portion of sulphurated hydrogen.

5. Copper is capable of existing in the state of a hydrogenated sulphuret; its precipitate seems to be nearly in that state, or at least to be a sulphuret with excess of sulphur.

6. Iron also forms a hydrogenated sulphuret, which is soluble in water, and has a deep green colour; but the precipitate of that metal by a hydrosulphuret is probably the black oxide combined with sulphur.

7. The precipitates of tin, lead, and zinc seem to be sulphurets.

8. The precipitate produced in antimonial solutions by hydrosulphuret of potass, is the only one of them all which has been hitherto examined with attention. It has an orange colour, and has been shewn by Ber-

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\* Stahl's *Opusc. Chim. Phys. Med.* p. 606.

thollet and Thenart to be a compound of oxide of antimony and super-sulphurated hydrogen. This compound, under the name of *kermes mineral*, acquired very great celebrity for its medical virtues about the beginning of the 18th century. The method of preparing it was first discovered by Glauber, and afterwards by Lemery the Elder; but it was first brought into vogue in France by a priest called Simon, who was taught the secret of preparing it by La Ligerie, a surgeon, to whom it had been communicated by a pupil of Glauber. The French government purchased the secret from La Ligerie, and published the process in 1720. It was very tedious and ill contrived, consisting in boiling repeatedly a very diluted solution of potass on sulphuret of antimony; a small portion of kermes precipitated as the solution cooled. The process of Lemery was therefore adopted by apothecaries. It is the following:

Sixteen parts of sulphuret of antimony, eight parts of potass of commerce, and one part of sulphur, are triturated together in a mortar, melted in a crucible, and the mass poured into an iron vessel. When cold it is pounded, and boiled in a sufficient quantity of water, and the solution is filtered while hot. On cooling, it deposits the kermes abundantly in the state of a yellow powder, which is edulcorated with a sufficient quantity of water, and dried: Or six parts of potass may be dissolved in twenty parts of water, and to this solution, previously made boiling hot, one part of pounded sulphuret of antimony may be added. The solution, well agitated, boiled for seven or eight minutes, and filtered while hot, deposits on cooling abundance of kermes.

This powder occupied a good deal of the attention of

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chemists. Bergman first demonstrated that it contained sulphurated hydrogen; but it was Berthollet who first pointed out its true composition. From the analysis of Thenart it follows that it is composed of

20.30 sulphurated hydrogen  
4.15 sulphur  
72.76 brown oxide of antimony  
2.79 water and loss

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100.00 \*

When this substance is exposed to the air, it gradually absorbs oxygen, and becomes white.

Sulphur,  
auratum.

After the mineral kermes has precipitated from its solution prepared by either of the formulas above described, if an acid be added to the liquid, another precipitate is produced of an orange colour, hence called *sulphur auratum*. According to the analysis of Thenart, it is composed of

17.87 sulphurated hydrogen  
68.30 orange oxide  
12.00 sulphur

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98.17 †

The sulphur seems to be only mechanically mixed; consequently the *sulphur auratum* is a hydrosulphuret of antimony. Goettling has proposed the following process for obtaining this compound: Two parts of sulphuret of antimony and three parts of sulphur well mixed are dissolved in a boiling solution of pure potass; the solution is then diluted with water, and precipitated by means of weak sulphuric acid ‡.

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\* *Ann. de Chim.* xxxii. 268.

† *Ibid.*

‡ Bergman iii. 172.



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## CHAP. V.

### OF SOAPS.

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THE fixed oils have the property of combining with alkalies, earths and metallic oxides, and of forming with these bodies a class of compounds which have received the name of *soaps*. As these soaps differ from each other very materially, according as their base is an alkali, an earth, or an oxide, it will be proper to consider each set separately. This will be the subject of the three following Sections.

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### SECT. I.

#### OF ALKALINE SOAPS.

As there are a great number of fixed oils, all or most of which are capable of combining with alkalies, earths, and oxides, it is natural to suppose that there are as many genera of alkaline soaps as there are oils. That there are differences in the nature of soaps corresponding to the oil which enters into their composition, is certain; but these differences are not of sufficient importance to require a particular description. It will

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be sufficient therefore to divide the alkaline soaps into as many species as there are alkalies, and to consider those soaps which have the same alkaline base, but differ in their oil, as varieties of the same species.

*Sp. 1. Soap of Soda, or Hard Soap.*

History.

THE word *soap* (*sapo*, σαπων) first occurs in the works of Pliny and Galen, and is evidently derived from the old German word *sepe*\*. Pliny informs us that soap was first discovered by the Gauls; that it was composed of tallow and ashes; and that the German soap was reckoned the best†.

Preparation.

Soap may be prepared by the following process: A quantity of the soda of commerce is pounded and mixed in a wooden vessel, with about a fifth part of its weight of lime, which has been slacked and passed through a sieve immediately before. Upon this mixture a quantity of water is poured, considerably more than what is sufficient to cover it, and allowed to remain on it for several hours. The lime attracts the carbonic acid from the soda, and the water becomes strongly impregnated with the pure alkali. This water is then drawn off by means of a stop-cock, and called the *first ley*. Its specific gravity should be about 1.200.

Another quantity of water is then to be poured upon the soda, which, after standing two or three hours, is also to be drawn off by means of the stop-cock, and called the *second ley*.

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\* Beckman's *History of Inventions*, iii. 239.—A similar word is still used by the common people of Scotland.

† Pliny, lib. xviii. c. 51.

Another portion of water is poured on; and after standing a sufficient time, is drawn off like the other two, and called the *third ley*.

Another portion of water may still be poured on, in order to be certain that the whole of the soda is dissolved; and this weak ley may be put aside, and employed afterwards in forming the first ley in subsequent operations.

A quantity of oil, equal to six times the weight of the soda used, is then to be put into the boiler, together with a portion of the *third* or *weakest ley*, and the mixture must be kept boiling and agitated constantly by means of a wooden instrument. The whole of the third ley is to be added at intervals to the mixture; and after it is consumed, the *second ley* must be added in the same manner. The oil becomes milky, combines with the alkali, and after some hours it begins to acquire consistence. A little of the *first ley* is then to be added, not forgetting to agitate the mixture constantly. Portions of the first ley are to be added at intervals; the soapy substance acquires gradually greater consistency, and at last it begins to separate from the watery part of the mixture. A quantity of common salt is then to be added, which renders the separation much more complete. The boiling is to be continued still for two hours, and then the fire must be withdrawn, and the liquor must be no longer agitated. After some hours repose the soap separates completely from the watery part, and swims upon the surface of the liquor. The watery part is then to be drawn off; and as it contains a quantity of carbonat of soda, it ought to be reserved for future use.

The fire is then to be kindled again; and, in order

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to facilitate the melting of the soap, a little water, or rather weak ley, is to be added to it. As soon as it boils, the remainder of the first ley is to be added to it at intervals. When the soap has been brought to the proper consistence, which is judged of by taking out small portions of it and allowing it to cool, it is to be withdrawn from the fire, and the watery part separated from it as before. It is then to be heated again, and a little water mixed with it, that it may form a proper paste. After this let it be poured into the vessels proper for cooling it; in the bottom of which there ought to be a little chalk in powder, to prevent the soap from adhering. In a few days the soap will have acquired sufficient consistence to be taken out, and formed into proper cakes\*.

The use of the common salt in the above process is to separate the water from the soap; for common salt has a stronger affinity for water than soap has.

Olive oil has been found to answer best for making soap, and next to it perhaps tallow may be placed: but a great variety of other oils may be employed for that purpose, as appears from the experiments of the French chemists above quoted. They found, however, that linseed oil and whale oil were not proper for making *hard soaps*, though they might be employed with advantage in the manufacture of *soft soaps*. Whale oil has been long used by the Dutch for this last purpose.

Soap may also be made without the assistance of heat; but in that case a much longer time and a larger proportion of alkali is necessary.

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\* See the Memoir of Darcet, Lelievre, and Pelletier, in the *Ann. de Chim.* xix. 253.



Manufacturers have contrived various methods of sophisticating soap, or of adding ingredients which increase its weight without increasing its value. The most common substance used for that purpose is water; which may be added in considerable quantities, especially to soap made with tallow (the ingredient used in this country), without diminishing its consistency. This fraud may be easily detected, by allowing the soap to lie for some time exposed to the air. The water will evaporate from it, and its quantity will be discovered by the diminution of the weight of the soap. As soap sophisticated in this manner would lose its water by being kept, manufacturers, in order to prevent that, keep their soap in saturated solutions of common salt; which do not dissolve the soap, and at the same time, by preventing all evaporation, preserve, or rather increase, the weight of the soap. Messrs Darcet, Lelievre, and Pelletier, took two pieces equal in weight of soap sophisticated in this manner, and placed the one in a dry place in the open air, and the other in a saturated solution of common salt. After a month the first had lost 0.56 of its weight, the other had gained about 0.10 parts\*. Various other methods have been fallen upon to sophisticate soap; but as they are not generally known, it would be doing an injury to the public to describe them here.

Different chemists have analysed soap, in order to ascertain the proportions of its ingredients; but the result of their experiments is various, because they used soap containing various quantities of water. From the experiments of Darcet, Lelievre, and Pelletier, it ap-

Analysis.

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\* *Ann. de Chim.* xix. 330.

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pears that soap newly made and exposed to sale contains

60.94 oil  
8.56 alkali  
30.50 water

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100.00

Soap is soluble both in water and in alcohol. Its properties as a detergent are too well known to require any description.

Soap made with tallow and soda has a white colour, and is therefore known by the name of *white soap*: but it is usual for soap-makers, in order to lower the price of the article, to mix a considerable portion of rosin with the tallow; this mixture forms the common *yellow soap* of this country.

*Sp. 2. Soap of Potass or Soft Soap.*

Formation.

POTASS may be substituted for soda in making soap, and in that case precisely the same process is to be followed. It is remarkable, that when potass is used, the soap does not assume a solid form; its consistence is never greater than that of hog's lard. This is what in this country is called *soft soap*. Its properties as a detergent do not differ materially from those of *hard soap*, but it is not nearly so convenient for use. The alkali employed by the ancient Gauls and Germans in the formation of soap was potass; hence we see the reason that it is described by the Romans as an unguent. The oil employed for making soft soap in this country is whale oil. A little tallow is also added, which, by peculiar management, is dispersed through the soap in fine white spots.

Some persons have affirmed that they knew a me-

thod of making hard soap with potass. Their method is this: After forming the soap in the manner above described, they add to it a large quantity of common salt, boil it for some time, and the soap becomes solid when cooled in the usual way. That this method may be practised with success has been ascertained by Messrs Darcet, Lelievre, and Pelletier; but then the hard soap thus formed does not contain potass but soda; for when the common salt (muriat of soda) is added, the potass of the soap decomposes it, and combines with its muriatic acid, while at the same time the soda of the salt combines with the oil, and forms hard soap: and the muriat of potass formed by this double decomposition is dissolved in water, and drawn off along with it\*.

Chaptal has lately proposed to substitute wool in place of oil in the making of soap. The ley is formed in the usual manner, and made boiling hot, and shreds of woollen cloth of any kind are gradually thrown into it; they are soon dissolved. New portions are to be added sparingly, and the mixture is to be constantly agitated. When no more cloth can be dissolved, the soap is made†. This soap is said to have been tried with success. It might doubtless be substituted for soap with advantage in several manufactures, provided it can be obtained at a cheaper rate than the soaps at present employed.

Soap of  
wool.

Some time ago a proposal was made to substitute the muscles of fish instead of tallow or oil in the manufacture of soap; but the experiments of Mr Jamieson have demonstrated that they do not answer the purpose‡.

Fish soap.

\* *Ann. de Chim.* xix. 322.

† *Ibid.* xxi. 27.

‡ *Nicholson's Journal*, iii. 113.

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*Sp. 3. Soap of Ammonia.*

THIS soap was first particularly attended to by Mr Berthollet. It may be formed by pouring carbonat of ammonia on soap of lime. A double decomposition takes place, and the soap of ammonia swims upon the surface of the liquor in the form of an oil; or it may be formed with still greater ease by pouring a solution of muriat of ammonia into common soap dissolved in water.

It has a more pungent taste than common soap. Water dissolves a very small quantity of it; but it is easily dissolved in alcohol. When exposed to the air, it is gradually decomposed. The substance called *volatile liniment*, which is employed as an external application in rheumatisms, colds, &c. may be considered as scarcely any thing else than this soap.

All the alkaline soaps agree in the properties of solubility in water and alcohol, and in being powerful detergents.

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SECT. II.

OF EARTHY SOAPS.

THE earthy soaps differ essentially from the alkaline in their properties. They are insoluble in water, and incapable of being employed as detergents. They may be formed very readily by mixing common soap with a solution of an earthy salt; the alkali of the soap combines with the acid of the salt, while the earth and oil



unite together and form an earthy soap. Hence the reason that all waters holding an earthy salt are unfit for washing. They decompose common soap, and form an earthy soap insoluble in water. These waters are well known by the name of *hard* waters. Hitherto the earthy soaps have been examined by Mr Berthollet only.

*Sp. 1. Soap of Lime.*

THIS soap may be formed by pouring lime-water into a solution of common soap. It is insoluble both in water and alcohol. Carbonat of fixed alkali decomposes it by compound affinity \*. It melts with difficulty, and requires a strong heat.

Soap of barytes and of strontian resemble almost exactly the soap of lime.

*Sp. 2. Soap of Magnesia.*

THIS soap may be formed by mixing together solutions of common soap and sulphat of magnesia. It is exceedingly white. It is unctuous, dries with difficulty, and preserves its whiteness after desiccation. It is insoluble in boiling water. Alcohol and fixed oil dissolve it in considerable quantity. Water renders its solution in alcohol milky. A moderate heat melts it; a transparent mass is formed, slightly yellow, and very brittle \*.

*Sp. 3. Soap of Alumina.*

THIS soap may be formed by mixing together solu-

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\* Thouvenel.

† Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.

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tions of alum and of common soap. It is a flexible soft substance, which retains its suppleness and tenacity when dry. It is insoluble in alcohol, water, and oil. Heat easily melts it, and reduces it to a beautiful transparent yellowish mass \*.

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### SECT. III.

#### OF METALLIC SOAPS AND PLASTERS.

METALLIC OXIDES are capable of combining with oils by two different processes: 1. By mixing together a solution of common soap with a metallic salt. 2. By uniting the metallic oxide with the oil directly either cold or by the assistance of heat. The first of these combinations is called a *metallic soap*; the second, a *plaster*. Let us consider each of these in their order.

##### I. *Metallic Soaps.*

THESE soaps have been examined by Mr Berthollet; who has proposed some of them as paints, and others as varnishes; but it does not appear that any of them has been hitherto applied to these purposes.

1. *Soap of mercury* may be formed by mixing together a solution of common soap and of corrosive muriatic of mercury. The liquor becomes milky, and the soap of mercury is gradually precipitated. This soap is viscid, not easily dried, loses its white colour when exposed to the air, and acquires a slate colour, which

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\* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.

gradually becomes deeper, especially if exposed to the sun or to heat. It dissolves very well in oil, but sparingly in alcohol. It readily becomes soft and fluid when heated \*.

2. *Soap of zinc* may be formed by mixing together a solution of sulphat of zinc and of soap. It is of a white colour, inclining to yellow. It dries speedily, and becomes friable †.

3. *Soap of cobalt*, made by mixing nitrat of cobalt and common soap, is of a dull leaden colour, and dries with difficulty, though its parts are not connected.

Mr Berthollet observed, that towards the end of the precipitation there fell down some green coagula, much more consistent than soap of cobalt. These he supposed to be a soap of nickel, which is generally mixed with cobalt ‡.

4. *Soap of tin* may be formed by mixing common soap with a solution of tin in nitro-muriatic acid. It is white. Heat does not fuse it like other metallic soaps, but decomposes it §.

5. *Soap of iron* may be formed by means of sulphat of iron. It is of a reddish brown colour, tenacious, and easily fusible. When spread upon wood, it sinks in and dries. It is easily soluble in oil, especially of turpentine. Berthollet proposes it as a varnish ||.

6. *Soap of copper* may be formed by means of sulphat of copper. It is of a green colour, has the feel of a resin, and becomes dry and brittle. Hot alcohol renders its colour deeper, but scarcely dissolves it. Ether dissolves it, liquefies it, and renders its colour deeper and

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\* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.

† Ibid.

‡ Ibid.

§ Ibid.

|| Ibid.

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more beautiful. It is very soluble in oils, and gives them a pleasant green colour \*.

7. *Soap of lead* may be formed by means of acetite of lead. It is white, tenacious, and very adhesive when heated. When fused it is transparent, and becomes somewhat yellow if the heat be increased †.

8. *Soap of silver* may be formed by means of nitrat of silver. It is at first white, but becomes reddish by exposure to the air. When fused, its surface becomes covered with a very brilliant iris; beneath the surface it is black ‡.

9. *Soap of gold* may be formed by means of muriat of gold. It is at first white, and of the consistence of cream. It gradually assumes a dirty purple colour, and adheres to the skin so that it is difficult to efface the impression §.

10. *Soap of manganese* may be formed by means of sulphat of manganese. It is at first white, but it assumes in the air a reddish colour, owing evidently to the absorption of oxygen. It speedily dries to a hard brittle substance, and by liquefaction assumes a brown blackish colour ||.

## II. Plasters.

### Properties.

PLASTERS are combinations of oils and metallic oxides destined to be spread upon leather or cloth, and in that state to be applied as a covering of ulcers, &c. They ought to be solid bodies, not so hard as to refuse to spread easily and equally, nor so soft as to run into oil when heated by the skin. They ought to admit of be-

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\* Berthollet, *Mém. Par.* 1780, or Nicholson's *Journal*, i. 170.

† Ibid.

‡ Ibid.

§ Ibid.

|| Ibid.



ing easily kneaded when heated with the hand, to adhere firmly to the skin, but to be capable of being removed without leaving behind them any stain. Without these properties they do not answer the purpose for which they are destined, which is chiefly adhesion.

The only chemist who has hitherto examined plasters with attention is Deyeux, to whom we are indebted for some excellent observations on the method of preparing them\*.

The oxides hitherto employed for making plasters are those of lead; and *litharge* is usually considered as the best adapted for that purpose of any of these oxides. But the oxides of several of the other metals, as bismuth and mercury, are also capable of forming plasters, and might perhaps in some cases be employed with advantage. Some metallic oxides, however, as those of iron, are not susceptible of that kind of combination with oils which constitutes plasters†.

Oxides  
used.

All the fixed oils are capable of forming plasters; but they do not all form plasters with the same properties. The *drying* oils, linseed oil for instance, form plasters of a much softer consistency than the *fat* oils; but these last acquire the same properties as the drying oils if they be combined with mucilage. Thus olive oil, boiled for some time with linseed or fenugrec, forms with litharge plasters as soft as those composed of linseed oil and litharge. According to Deyeux, olive oil answers better for plasters than any other.

Oils.

There are three different ways of forming plasters. The first consists in simply mixing together oil and litharge in proper proportions, and allowing the mixture

Formation.  
1st Process.

\* *Ann. de Chim.* xxxiii. 50.

† Deyeux, *Ibid.*

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to remain a considerable time in the common temperature of the atmosphere, agitating it occasionally. The oxide gradually loses its colour and combines with the oil, and the mixture acquires consistence. This process is tedious, and does not furnish plasters sufficiently solid to answer the purposes for which they are intended. It is not therefore employed.

**2d Process.** The second method consists in throwing the oxide into the oil while boiling. Plasters formed by this process have always a deep colour and a peculiar odour, occasioned by the decomposition of a portion of the oil. When this process is followed, it is necessary that the oxide should be in the state of a fine powder; and that by agitation it should be made to combine with the oil as fast as possible, otherwise the metal will be revived altogether, in consequence of the strong tendency which oil has to combine with oxygen when raised to a high temperature.

**3d Process.** The third method is most frequently practised, because it is not liable to the same inconveniences as the other two. This method consists in boiling the oil and the oxide together in a sufficient quantity of water. By this liquid the heat is moderated at first till the oil and oxide combine, which prevents the revival of the metal; and afterwards, when the water is dissipated, the temperature is sufficiently high to give the plaster the requisite consistency.

Plasters, when long kept, become often too hard to be fit for use, especially if the requisite proportion of oil has not been employed at first. This defect is easily remedied, by melting them with a small portion of new oil. Plasters, when long kept, likewise change their colour, and most of their sensible properties;

owing either to the absorption of oxygen, or to some change produced in their component parts by the action of the air.

Chap. VI.

## CHAP. VI.

### REMARKS ON THE SECONDARY COMPOUNDS.

THE secondary compounds are incomparably more numerous than the primary; because they approach much nearer the actual component parts of the mineral, vegetable, and animal kingdoms. Indeed a very considerable proportion of them exist native, especially in the mineral kingdom; and that number will no doubt increase as the science of chemistry extends its bounds.

Few of the secondary compounds have that activity, that violent action, upon other bodies, which distinguish the primary compounds. In this respect they bear a strong resemblance to the simple substances. Sulphur, for instance, is a body which has scarcely any taste, and which acts but feebly upon animals, and not at all perceptibly upon vegetables and minerals; and oxygen, though it undoubtedly merits the appellation of an active body, shews neither in its taste nor in its action on animals and vegetables any thing which deserves the name of acrid or caustic; but sulphuric acid, though composed of these two inoffensive bodies, is one of the most active and corrosive substances known, and burns and decomposes almost all the animal and vegetable

Secondary compounds resemble simple bodies.

Book II.  
Division II.

bodies which are exposed to its influence. Potass is, if possible, still more corrosive; even the hardest mineral is unable to resist its action. But sulphat of potass, though composed of these two formidable bodies, is not more active than sulphur itself. This singular correspondence between simple substances and secondary compounds, and the striking contrast between them and the primary compounds, deserve attention. It demonstrates to us, that the activity of bodies is not proportional to their simplicity, as has been hitherto supposed; and that there is some other cause besides combination with other bodies to blunt their energy.

None of  
them gaseous

Several of the simple bodies exist commonly in the state of gas: this is the case also with the primary compounds; but no gaseous body is found among the secondary compounds, and only a comparatively small number of liquid bodies. Almost all of them are solid, and probably every one of them is susceptible of assuming that form. Hence we see that gaseous bodies have all of them a considerable degree of simplicity; none of them, as far as is known, containing more than two component parts, if we omit the consideration of caloric and light altogether; or three component parts, if we include these bodies.

Or combustible.

None of the secondary compounds are, properly speaking, combustible. The soaps, indeed, and the vegetable-acid salts, are susceptible of undergoing a kind of combustion, but not till they have been previously decomposed by heat; and even then their combustion is not to be compared to that of some of the simple substances and primary compounds. Two genera of salts, namely, the nitrats and oxy-muriats, are supporters of combustion in a remarkable degree, occasioning violent detonations when triturated or heated along with com-



bustibles. Many of the metallic salts are doubtless susceptible of supporting combustion as well as these genera, though hitherto the experiment has not been tried except upon a small number. Chap. VI.

The secondary compounds have been investigated with more precision than any other class of bodies belonging to chemistry; and their formation and decomposition are more completely in the power of the chemist. The greater number of them may be formed and decomposed at pleasure; and approaches have been made towards ascertaining the proportions of the component parts of several of them. Accordingly it is from them that almost all our notions of the nature of affinity have been derived. It is to them that we have always recourse to illustrate these notions, or to put them to the test of experiment. What have been called *tables of affinity*, are nothing else than lists of the substances by which certain secondary compounds may be decomposed, or of the precipitations which take place when different secondary compounds are mixed together. It was necessary therefore to be acquainted with these bodies, and to know the mutual changes which they are capable of producing on each other; the decompositions of which they are susceptible, and the proportions of their component parts, before entering upon the consideration of *affinity*; which may be considered as constituting in reality the whole of the scientific part of chemistry, and as comprehending under it the general principles to which the immense mass of facts enumerated in the two preceding Books may be referred, and under which they may be arranged. We are now therefore prepared for entering upon this important subject, which will employ the whole of the succeeding Book.

Better  
known  
than other  
bodies.

## BOOK III.

OF

## A F F I N I T Y.

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**Book III.** **I**N the two preceding Books the different substances which occupy the attention of the chemists have been enumerated, their properties have been described, and the changes which they produce on each other have been fully detailed. We are thus in possession of the immense body of facts of which the science of chemistry is composed; they have been arranged in that order which seemed most proper for shewing their mutual dependence on each other; and referred to a small number of general heads, that they might be remembered with facility or consulted without difficulty. It were to be wished that chemical phenomena could be referred to a few general laws, and shewn to be the necessary results of these laws. It were to be wished that we knew the nature of these laws so precisely, as to be able to foretel beforehand the changes which result from the mutual action of bodies in every particular circumstance. This would save us the trouble of learning in detail an immense number of insulated facts which at

Chemical  
laws

present are necessary for the practice of chemistry ; it would enable us to apply the science with more effect to the arts and manufactures ; it would enable us to trace the chemical changes which are going on in the atmosphere and the earth to their origin, and to foresee the future changes to which they are liable ; and thus to form what has hitherto been attempted in vain, a complete theory of meteorology and geology.

Unfortunately the efforts of philosophers to establish these general principles have not hitherto been attended with complete success ; partly owing to the difficulty of the subject, and partly to the unaccountable negligence of the greater number of chemists who have been more anxious to ascertain particular facts than to investigate general principles, and who have often seemed to look upon general principles as altogether foreign to their science. Happily this has not been the case with all chemists. Several, and these the most illustrious, have carefully classified the phenomena, and referred them under general heads ; and if they have not succeeded in discovering laws sufficiently comprehensive to include all the chemical phenomena, have at least pointed out several pretty general ones, from the knowledge of which the mutual action of many bodies on each other may, in not a few cases, be foreseen, even prior to experiment. Among these philosophers, none stands higher than Bergman, who was not less distinguished by his industry and enthusiasm, than by his enlarged views and the happy acuteness with which he drew general conclusions. To Black and Lavoisier we are indebted for two of the most general and most important laws hitherto discovered in chemistry. Much has been done by Kirwan, whose profound knowledge,

Still imperfectly known.

## Book III.

fortunately for the science, almost constantly leads him to general views. Morveau has been no less distinguished in this important career; with a mind capable of the most comprehensive range, and the most profound views, he has classified the most difficult phenomena, and thrown light upon the abstrusest part of the science. And Berthollet has lately reviewed the general doctrines of chemistry with his usual sagacity; and has not only corrected various errors which had passed current without detection, but has pointed out several new laws of very great importance.

The general principles of chemistry shall form the subject of this Third Book, which will be divided into four Chapters. In the *first* Chapter we shall consider the nature of AFFINITY in general; in the *second*, we shall examine the affinity which HOMOGENEOUS bodies exert on each other; in the *third*, the affinity exerted by HETEROGENEOUS bodies; and in the *fourth*, the nature of REPULSION, which often acts as an antagonist to affinity.



## CHAP. I.

## OF AFFINITY IN GENERAL.

1. ALL the great bodies which constitute the solar system are urged towards each other by a force which preserves them in their orbits and regulates their motions. This force has received the name of *attraction*. Attraction  
 Its nature is unknown: whether it be inherent in these bodies themselves, or the consequence of some foreign agent, are questions altogether beyond the reach of philosophy, because we have no method of deciding the point. One would be more inclined to the first supposition than to the other, as we can conceive no foreign agent sufficient to explain the planetary motions unless an intelligent one; and for any thing which we know to the contrary, it 'was as easy for the Creator to have bestowed on the planets the power of acting on each other at a distance, as the power of being acted on and receiving motion from other substances.

2. Sir Isaac Newton demonstrated, that this planetary Universal.  
 attraction is the same with *gravitation*, or that force by which a heavy body is urged towards the earth; that it is possessed, not only by the planets as wholes, but by all their component parts also; that it is mutual; that it extends to indefinite distances; and that all bodies, as far as is known, are possessed of it.

3. When two bodies are brought within a certain

## Book III.

distance, they adhere together, and require a considerable force to separate them. This is the case, for instance, with two polished pieces of marble or glass. When a piece of metal, or indeed almost any body whatever, is plunged into water and drawn out again, its surface is moistened, that is to say, part of the water adheres to it. When a rod of gold is plunged into mercury, it comes out stained indelibly of a white colour, because it retains and carries with it a portion of the mercury. Hence it is evident that there is a force which urges these bodies towards each other and keeps them together; consequently there is an attraction between them. Bodies, therefore, are not only attracted towards the earth and the planetary bodies, but towards each other. The nature of this attraction cannot be assigned any more than that of gravitation; but its existence is equally certain, as far at least as regards by far the greater number of bodies.

4. In all cases we find the particles of matter united together in masses, differing indeed from each other in magnitude, but containing all of them a great number of particles. These particles remain united, and cannot be separated without the application of a considerable force; consequently they are kept together by a force which urges them towards each other, since it opposes their separation. Consequently this force is an *attraction*.

Thus we see that there is a certain unknown force which urges bodies towards each other; a force which acts not only upon large masses of matter as the sun and the planets, but upon the smaller component parts of these bodies, and even upon the particles of which these bodies are composed. Attraction, therefore, as far as we know, extends to all matter, and exists mu-

ually between all matter. It is not annihilated at how great a distance soever we may suppose bodies to be placed from each other, neither does it disappear, though they be placed ever so near each other. The nature of this attraction, or the cause which produces it, is altogether unknown, but its existence is demonstrated by all the phenomena of nature.

5. This attraction was long accounted for, by supposing that there existed a certain unknown substance which impelled all bodies towards each other; a hypothesis to which philosophers had recourse, from an opinion long admitted as a first principle, "that no body can act where it is not;" as if it were more difficult to conceive why a change is produced in a body by another which is placed at a great distance, than why it is produced by one which is situated at a small distance. It is not only impossible to explain the phenomena of attraction by impulsion, but it is as difficult to conceive how bodies should be urged towards each other by the action of an external substance, as how they should be urged towards each other by a power inherent in themselves. The fact is, that we can neither comprehend the one nor the other; nor can any reason be assigned why the Almighty might not as easily bestow upon matter the power of acting upon matter at a distance, as the power of being acted upon and changed by matter in actual contact.

Ascribed to  
impulsion,

But with-  
out reason,

But farther, we have no reason for supposing that bodies are ever in any case actually in contact. For all bodies are diminished in bulk by cold, that is to say, their particles are brought nearer each other, which would be impossible, unless they had been at some distance before the application of the cold. Almost all bodies are diminished in bulk by pressure, and conse-

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quently their particles are brought nearer each other; and the diminution of bulk is always proportional to the pressure. Newton has shown that it required a force of many pounds to bring two glasses within the 800th part of an inch of each other; that a much greater was necessary to diminish that distance; and that no pressure whatever was capable of diminishing it beyond a certain point. Consequently there is a force which opposes the actual contact of bodies; a force which increases inversely as some power or function of the distance, and which no power whatever is capable of overcoming. Boscovich has demonstrated, that a body in motion communicates part of its motion to another body before it actually reaches it. Hence we may conclude that, as far as we know, there is no such thing as actual contact in nature, and that bodies of course always act upon each other at a distance. Even impulsion, therefore, or pressure, is an instance of bodies acting on each other at a distance, and therefore is no better explanation of attraction than the supposition that it is an inherent power. We must therefore be satisfied with considering attraction as an unknown power, by which all bodies are urged towards each other. It is a power which acts constantly and uniformly in all times and places, and which is always diminishing the distance between bodies, unless, when they are prevented from approaching each other by some other force equally powerful.

Of two  
kinds.

6. The change which attraction produces on bodies is a diminution of their distance. Now the distances of bodies from each other are of two kinds, either too small to be perceived by our senses, or great enough to be easily perceived and estimated. In the first case,



the change of distance produced by attraction must be insensible, in the second case it must be visible. Hence the attractions of bodies, as far as regards us, naturally divide themselves into two classes. 1. Those which act at sensible distances. 2. Those which act at insensible distances. The first class obviously applies to bodies in masses of sensible magnitude; the second class must be confined to the particles of bodies, because they alone are at insensible distances from each other.

7. It has been demonstrated, that the intensity of the first class of attractions varies with the mass and the distance of the attracting bodies. It increases with the mass of these bodies, but diminishes as the distance between them increases. Hence we see that in this class of attractions every particle of the attracting bodies acts, since the sum of the attracting force is always proportional to the number of particles in the attracting bodies. Why it diminishes as the distance increases, it is impossible to say; but the fact is certain, and is almost incompatible with the supposition of impulsion as the cause of attraction. The rate of variation has been demonstrated to be inversely as the square of the distance in all cases of attraction belonging to the first class.

1. At sensible distances.

8. The attractions belonging to the first class must be as numerous as there are bodies situated at sensible distances; but it has been ascertained that they may be all reduced to three different kinds; namely, 1. Gravitation; 2. Electricity; 3. Magnetism. The first of these has been shewn by Newton to belong to all matter as far as we have an opportunity of examining, and therefore to be universal. The other two are partial, being confined to certain sets of bodies, while the rest

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of matter is destitute of them; for it is well known that all bodies are not electric, and that scarcely any bodies are magnetic, except iron, cobalt, nickel, and perhaps manganese.

The intensity of these three attractions increases as the mass of the attracting bodies, and diminishes as the square of the distance increases. The first extends to the greatest distance at which bodies are known to be separated from each other. How far electricity extends has not been ascertained; but magnetism extends at least as far as the semidiameter of the earth. All bodies possess gravity; but it has been supposed that the other two attractions are confined to two or three subtile fluids, which constitute a part of all those bodies which exhibit the attractions of electricity or magnetism. This may be so; but it has not and scarcely can be demonstrated.

9. The absolute force of these attractions in given bodies can only be measured by the force necessary to counteract the effect of these attractions, or by the space which given bodies, acted on merely by these attractions, traverse in a given time. If we compare the different bodies acted on by gravitation, we shall find that the absolute force of their gravitation towards each other is in all cases the same, provided their distances from each other and their mass be the same; but this is by no means the case with electrical and magnetic bodies. In them the forces by which they are attracted towards each other, called electricity and magnetism, are exceedingly various, even when the mass and the distance are the same. Sometimes these forces disappear almost entirely; at other times they are exceedingly intense. Gravity therefore is a force inherent in

bodies ; electricity and magnetism not so ; a circumstance which renders the opinion of their depending upon peculiar fluids exceedingly probable. If we compare the absolute force of these three powers with each other, it would appear that the intensity of the two last, every thing else being equal, is greater than that of the first ; but their relative intensity cannot be compared, and is therefore unknown. Hence it follows that these different attractions, though they follow the same laws of variation, are not the same in kind.

10. The attractions between bodies at insensible distances, and which of course are confined to the particles of matter, have been distinguished by the name of *affinity*, while the term *attraction* has been more commonly confined to cases of sensible distance. Now the particles of matter are of two kinds, either *homogeneous* or *heterogeneous*. By homogeneous particles, I mean particles which compose the same body ; thus all particles of iron are homogeneous. By heterogeneous particles are meant those which compose different bodies ; thus a particle of iron and a particle of lead are heterogeneous.

2. Affinity

Homogeneous affinity urges the homogeneous particles towards each other, and keeps them at insensible distances from each other ; and consequently is the cause why bodies almost always exist united together, so as to constitute masses of sensible magnitude. This affinity is usually denoted by the term *cohesion*, and sometimes by *adhesion* when the surfaces of bodies are only referred to. Homogeneous affinity is nearly universal ; as far as is known, caloric and light only are destitute of it.

Heterogeneous affinity urges heterogeneous particles

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towards each other, and keeps them at insensible distances from each other, and of course is the cause of the formation of new integrant particles composed of a certain number of heterogeneous particles. These new integrant particles afterwards unite by cohesion, and form masses of compound bodies. Thus an integrant particle of water is composed of particles of hydrogen and oxygen, urged towards each other, and kept at an insensible distance by heterogeneous affinity; and a mass of water is composed of an indefinite number of integrant particles of that fluid, urged towards each other by homogeneous affinity. Heterogeneous affinity is universal, as far as is known; that is to say, there is no body whose particles are not attracted by the particles of some other body; but whether the particles of all bodies have an affinity for the particles of all other bodies, is a point which we have no means of ascertaining. It is, however, exceedingly probable, and has been generally taken for granted; though it is certainly assuming more than even analogy can warrant.

Increases  
with the  
mass

II. Affinity, like sensible attraction, varies with the mass and the distance of the attracting bodies. That cohesion varies with the mass, cannot indeed be ascertained; because we have no method of varying the mass without at the same time altering the distance. But in cases of the adhesion of the surfaces of homogeneous bodies, which is undoubtedly an instance of homogeneous affinity, it has been demonstrated, that the force of adhesion increases with the surface, that is to say, with the mass; for the number of adhering particles must increase with the surface.

That heterogeneous affinity increases with the mass, has been observed long ago in particular instances, and



has been lately demonstrated by Berthollet to hold in every case; thus a given portion of water is retained more obstinately by a large quantity of sulphuric acid than by a small quantity. Oxygen is more easily abstracted from those oxides which are oxidated to a maximum, than from those which are oxidated to a minimum; that is to say, that a large mass of metal retains a given quantity of oxygen more violently than a small mass. Lime deprives potass of only a portion of its carbonic acid, and sulphuric acid deprives phosphoric acid of only a portion of the lime with which it is united in phosphat of lime. In these, and many other instances that might be enumerated, a small portion of one body is retained by a given quantity of another more strongly than a large quantity. And Berthollet has shewn, that in all cases a large quantity of a body is capable of abstracting a portion of another from a small portion of a third; how weak soever the affinity between the first and second of these bodies is, and how strong soever the affinity between the second and the third. Thus when equal quantities of the following bodies were boiled together,

- |                        |                       |
|------------------------|-----------------------|
| 1. { Sulphat of potass | 4. { Oxalat of lime   |
| { Potass               | { Potass              |
| 2. { Sulphat of potass | 5. { Phosphat of lime |
| { Soda                 | { Potass              |
| 3. { Sulphat of potass | 6. { Carbonat of lime |
| { Lime                 | { Potass              |

the uncombined base abstracted part of the acid from the base with which it was previously combined; though in every one of these instances it was retained by that base by an affinity considered as stronger. The same division of the base took place when equal quan-

Book III.     titles of oxalat of lime and nitric acid were boiled together.

Inversely  
as the dis-  
tance.

That the force of affinity increases as the distance diminishes, and the contrary, is obvious; for it becomes insensible whenever the distance is sensible, and on the other hand, becomes exceedingly great when the distance is exceedingly diminished. But the particular rate which this variation follows is still unknown, as we have no method of measuring either the distances at which it acts, or its relative intensity at these distances. Some have supposed that it follows a greater ratio than  $\frac{1}{d^2}$ , and that it diminishes at least as  $\frac{1}{d^3}$ , if not at some greater rate. But their reasoning has depended altogether upon the supposition that the particles of bodies united by affinity are in actual contact and loses its force, or at least a considerable part of it, if we suppose, what seems actually to be the case, that even then these particles are at a distance. Others have supposed that the intensity of affinity varies inversely as the square of the distance, resting chiefly upon the analogy of sensible attraction which follows that law. This is certainly a kind of presumption in favour of the opinion, and it must be allowed that no sufficient arguments have been advanced to prove that this law is incompatible with the phenomena of affinity. But neither, on the other hand, have any thing like proofs been advanced to show that affinity actually varies according to that law. The truth is, that at present the subject is beyond the reach of philosophy. We must therefore suspend our judgment altogether till future discoveries put it in our power to determine the point.

12. Affinity then agrees with sensible attraction in

every point which it has been hitherto possible to determine. Like sensible attraction, it increases with the mass, and diminishes as the distance augments; consequently we must conclude that attraction, whether it be sensible or insensible, is in all cases the same kind of force, and regulated by precisely the same general laws.

We have seen that sensible attraction, though in all cases the *same kind* of force, is not always the *very same* force; for though the mass and the distance of two bodies be equal, the absolute force by which they are attracted towards each other by gravitation is not equal to the force by which they are attracted towards each other by magnetism. The forces of sensible attraction are three in number, namely, gravitation, magnetism, and electricity; the first is always the same when the mass and distance are the same, but the two last vary even when the mass and distance continue unaltered.

The forces of affinity, though also the same in kind, are still more numerous than those of sensible attraction; for instead of three, they amount to as many as there are heterogeneous bodies. The rate, indeed, at which they vary when the distance of the attracting bodies increases or diminishes, is probably the same in all, and so is also their variation as far as it regards the mass. But even when both of these circumstances, as far as we can estimate them, are the same, the affinity of two bodies for a third is not the same. Thus barytes has a stronger affinity for sulphuric acid than potass has: for if equal quantities of each be mixed with a small portion of sulphuric acid, the barytes seizes a much greater proportion of the acid than the potass does. This difference in intensity extends to particles of all bodies; for there are scarcely any two bodies whose

Affinity varies in intensity,

## Book III.

particles have precisely the same affinity for a third, and scarcely any two bodies, the particles of each of which cohere together with exactly the same force.

It is this difference in intensity which constitutes the most important characteristic mark of affinity, and which explains the different decompositions and changes which one body occasions in others.

Thus it appears at first sight, that there are as many different affinities as there are bodies; and that affinity, instead of being one force, like gravitation, which is always the same when the circumstances are the same, consists of a variety of different forces, regulated, indeed, by the same kind of laws, but all of them different from each other. These affinities do not vary like magnetism and electricity, though the mass continues the same, but are always of equal intensity when other circumstances are equal. Hence it is reasonable to conclude that these affinities cannot, like magnetism and electricity, depend upon peculiar fluids, the quantity of which may vary, but that they are permanent forces, inherent in every atom of the attracting bodies.

13. It is very possible that this variation of intensity, which forms so remarkable a distinction between affinity and gravitation, may be only apparent and not real. For even in gravitation the intensity varies with the distance and the mass, and the same variation holds in affinity. But as the attraction of affinity acts upon bodies situated at insensible distances from each other, it is evident that, strictly speaking, we have no means of ascertaining that distance, and consequently that it may vary without our discovering the variation. But every such variation in distance must occasion a corresponding variation in the intensity of the attracting force. It



may be then that barytes attracts sulphuric acid with greater intensity than potass, because the particles of barytes, when they act upon the acid, are at a smaller distance from it than the particles of the potass are.

But it may be asked, Why, if barytes, potass, and sulphuric acid, are all mixed together in water, the particles of potass do not approach as near the acid as those of the barytes, since they are both at liberty to act? To this it may be answered, That in all probability they do approach each of them to the same *apparent* distance (if the expression be allowable), but that, notwithstanding, their *real* distance may continue different. The particles of bodies, how minute soever we suppose them to be, cannot be destitute of magnitude. They must have a certain length, breadth, and thickness, and therefore must always possess some particular figure or other. These particles, indeed, are a great deal too minute for us to detect their shape; but still it is certain that they must have some shape. Now it is very conceivable that the particles of every particular body may have a shape peculiar to themselves, and differing from the shape of the particles of every other body. Thus the particles of sulphuric acid may have one shape, those of barytes another, and those of potass a third.

Owing perhaps to the figure of the particles.

But if the particles of bodies have length, breadth, and thickness, we cannot avoid conceiving them as composed of an indeterminate number of still more minute particles or atoms. Now the affinity of two integrant particles for each other must be the sum of the attractions of all the atoms in each of these particles for all the atoms in the other: But the sum of these attractions must depend upon the number of attracting

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atoms, and upon the distance of these atoms from each other respectively; and this distance must depend upon the figure of the particles. For it is obvious, that if two particles, one of which is a tetrahedron and the other a cube, and which contain the same number of atoms, be placed at the same relative distance from a third particle, the sum of the distances of all the atoms of the first particle from all the atoms of the third particle, will be less than the sum of the distances of all the atoms of the second particle from those of the third. Consequently, in this case, though the apparent distance of the particles be the same, their real distance is different; and of course the cube will attract the third particle more strongly than the tetrahedron; that is, it will have a greater affinity for it than the tetrahedron.

But if the particles of bodies differ from each other in figure, they may differ also in density and in size; and this must also alter the absolute force of affinity, even when the distances and the figure of the attracting particles are the same. The first of these two circumstances indeed may be considered as a difference in the mass of the attracting bodies, and therefore may be detected by the weight of the aggregate; but the second, though also no less a variation in the mass, cannot be detected by any such method, though its effect upon the strength of affinity may be very considerable.

There is no doubt that, upon the supposition that such differences in the figure, density, and size of the attracting particles, really exist, and it is in the highest degree probable that they do exist, the variation in intensity which characterises chemical affinity may be accounted for, without supposing that the intensity of

Superior beings, when of late they saw  
+ mortal man unfold all nature's law,  
tamin'd such wisdom in an earthly shape,  
And shew'd a Newton as we shew an ape: —  
Pope's Ep: on man Ep: ij l 31





affinity as a force inherent in the ultimate particles or atoms of bodies is really different. The same thing may be applied to electricity and magnetism. It is certainly possible, therefore, that attraction, both sensible and insensible, may not only vary at the same rate, and according to the same laws, but be absolutely the same force inherent in the atoms of matter, modified merely by the number and situation of the attracting atoms. This is certainly possible; and it must be allowed that it corresponds well with those notions of the simplicity of Nature in which we are accustomed to indulge ourselves. But the truth is, that we are by no means good judges of the simplicity of Nature; we have but an imperfect glimpse here and there through the veil with which her operations are covered; and from the few points which we see, we are constantly forming conjectures concerning the whole of the machinery by which these operations are carried on. \* Superior beings smile at our theories as we smile at the reasonings of an infant; and were the veil which conceals the machine from our view to be suddenly withdrawn, we ourselves, in all probability, would be equally astonished and confounded at the wide difference between our theories and conjectures, and the real powers by which the machinery of the universe is moved. Let us not therefore be too precipitate in drawing general conclusions; but let us rather wait with patience till future discoveries enable us to advance farther; and satisfy ourselves in the mean time with arranging those laws of affinity which have been ascertained, without deciding whether it be the same force with gravitation, or a different one.

May be the  
same with  
gravitation.

14. The characteristic marks of affinity may be reduced to the three following:

Book III.  
Its characters.

I. It acts only at insensible distances, and of course affects only the particles of bodies.

II. This force is always the same in the same particles, but it is different in different particles.

III. This difference is modified considerably by the mass. Thus though A have a greater affinity for C than B has, if the mass of B be considerably increased while that of A remains unchanged, B becomes capable of taking a part of C from A.

But it will be necessary to consider the affinity of homogeneous and heterogeneous bodies more particularly. This will be the subject of the two following Chapters.

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CHAP II.OF HOMOGENEOUS AFFINITY.  

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WE never find the particles of bodies in a separate state: they are either combined with the particles of other bodies, or with each other, forming masses of greater or smaller magnitude. This last union is the effect of homogeneous affinity; which has been already defined to mean that force which unites homogeneous particles to each other. Now in homogeneous affinity there are two things which claim our attention: The first is the force itself by which the particles are kept united; the second is the form which the particles thus united are known to assume. The force is distinguished by the title of *cohesion*; and the form of the mass, when regular, has received the name of *crystal*. These two topics shall form the subject of the two following Sections, under the titles of *Cohesion* and *Crystallization*.

## SECT. I.

## OF COHESION.

THE force called *cohesion* is inherent in all the particles of all bodies, if we except caloric and light : For all bodies except these constantly exist in masses composed of an indefinite number of particles united together. This force possesses all the characters of affinity.

1. It acts only at insensible distances ; for whenever we remove the particles of a body to a perceptible distance from each other, they cease to cohere altogether.

Cohesion  
varies in  
different  
bodies.

2. Cohesion is exceedingly various in different bodies ; though in the same body, if other things be equal, it is always the same. Thus an iron rod is composed of particles of iron cohering so strongly, that it requires an enormous force to separate them. A smaller force is necessary to overcome the cohesion of lead, and a still smaller to separate the particles of chalk from each other. In short, there are scarcely two bodies whose particles cohere with the same force. The force of cohesion in solid bodies is measured by the weight necessary to break them, or rather to pull them asunder. Thus if a rod of glass be suspended in a perpendicular direction, and weights be attached to its lower extremity till the rod is broken by them, the weight attached to the rod just before it broke is the measure of the cohesive force of the rod. We are indebted to Muschenbroeck for the most complete set of experiments hitherto



to made upon the cohesive force of solid bodies. Sickengen has also examined the cohesion of several of the metals with much accuracy. The results of the labours of the first of these philosophers may be seen in the following TABLE\* :

## I. METALS.

Steel, bar . . . . .	135,000
Iron, bar . . . . .	74,500
Iron, cast . . . . .	50,100
Copper, cast . . . . .	28,600
Silver, cast . . . . .	41,500
Gold, cast . . . . .	22,000
Tin, cast . . . . .	4,440
Bismuth . . . . .	2,900
Zinc . . . . .	2,600
Antimony . . . . .	1,000
Lead, cast . . . . .	860

## II. ALLOYS.

Gold 2 parts, silver 1 part . . . . .	28,000
Gold 5, copper 1 . . . . .	50,000
Silver 5, copper 1 . . . . .	48,500
Silver 4, tin 1 . . . . .	41,000
Copper 6, tin 1 . . . . .	55,000
Brass . . . . .	51,000
Tin 3, lead 1 . . . . .	10,200
Tin 8, zinc 1 . . . . .	10,000
Tin 4, antimony 1 . . . . .	12,000
Lead 8, zinc 1 . . . . .	4,500
Tin 4, lead 1, zinc 1 . . . . .	13,000

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\* In this Table the numbers denote the pounds avoirdupois which are just sufficient to tear asunder a rod of each of the bodies whose base is an inch square.

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## III. WOODS.

Locust tree . . . . .	20,100
Jujeb . . . . .	18,500
Beech, oak . . . . .	17,300
Orange . . . . .	15,500
Alder . . . . .	13,900
Elm . . . . .	13,200
Mulberry . . . . .	12,500
Willow . . . . .	12,500
Ash . . . . .	12,000
Plum . . . . .	11,800
Elder . . . . .	10,000
Pomegranate . . . . .	9,750
Lemon . . . . .	9,250
Tamarind . . . . .	8,750
Fir . . . . .	8,330
Walnut . . . . .	8,130
Pitch pine . . . . .	7,656
Quince . . . . .	6,750
Cypress . . . . .	6,000
Poplar . . . . .	5,500
Cedar . . . . .	4,880

## IV. BONES.

Ivory . . . . .	16,270
Bone . . . . .	15,250
Horn . . . . .	8,750
Whalebone . . . . .	7,500
Tooth of sea calf . . . . .	4,075

Explained  
by Bosco-  
vich.

3. The nature of cohesion has been more happily explained by Boscovich than by any other philosopher. Indeed it forms the most beautiful and satisfactory part

of his theory. According to him, the particles of bodies cohere together when they are placed in the limit of repulsion and attraction. Two particles, when situated at a certain distance from each other, repel each other mutually; this repulsion gradually diminishes as the distance between the particles increases, till at last when the distance reaches a certain magnitude, the repulsion ceases altogether. If the distance be increased ever so little, the particles now, instead of repelling, attract each other; and this attraction increases with the distance, till at last it reaches its maximum. From this point it gradually diminishes, till at last, when the particles have acquired a certain distance, it vanishes altogether. If the distance be increased ever so little beyond that distance, the particles now again repel each other. He supposes that the insensible distance between two particles is divided into an indefinite number of portions of alternate repulsions and attractions.

Let the line AH (fig. 11.) represent the insensible distance between two particles; and let the ordinates of the curve  $IQ q q' q''$  represent the attracting and repelling forces of the two particles as the second moves along the line AB while the first remains in the point A. The ordinates of the curves situated above the line AH represent repulsive forces, and those below the line represent attracting forces. The points B, C, D, E, F, G, H, where the curve cuts the axis, represent the limits between repulsion and attraction. While the second particle is in any part of the line AB it is repelled: the repulsion increases as the particle approaches A, and at the point A it is infinite, because the line Aa is to be considered as an asymptote to the

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curve. At the point B the second particle is neither repelled nor attracted. In every part of the line BC it is attracted; and the attraction is a maximum at P, because there the ordinate PQ is a maximum. At the point C it is neither attracted nor repelled. In every part of CD it is repelled; in D it is neither attracted nor repelled; in DE it is attracted, and so on.

Now the points B, D, F, and H, are called by Boscovich limits of cohesion, because particles placed in these points remain unaltered, and even resist any force which endeavours to displace them. If they are driven nearer each other, they are again repelled to their former limit: on the other hand, if they are driven to a greater distance, they are again attracted to their former situation.

Boscovich supposes, that in all cases of cohesion the particles of the cohering body are so situated as to be in these limits of cohesion with respect to each other. According to this very ingenious theory, cohesion is not, properly speaking, a force, but the interval between two forces. And even if we were to modify the theory a little, still we must consider cohesion as the balancing of two opposite forces, either of which becomes prevalent according as the cohering particles are urged nearer each other or forced to a greater distance. Consequently, if we were to speak with precision, *cohesion* is not itself a force, but the absence of a force. What has been hitherto called the *force of cohesion*, is the attraction which prevents the cohering particles from separating from each other, and which begins to act; or, more precisely, which becomes prevalent when the particles are urged to a greater distance from each other.



4. Boscovich has shewn, in a very satisfactory manner, how all the varieties of cohesion may be produced by the differences in the size, figure, and density, of the cohering particles \*. It deserves attention, that in most cases the cohesive force of simple bodies is greater than that of compound bodies. To this indeed there are a great number of exceptions, but the observation holds in a variety of instances. All the metals cohere very strongly; the diamond probably coheres with no less force, if we can judge from its hardness; and the cohesion of sulphur is also very considerable. Thus if we except phosphorus, all the simple substances are remarkable for cohesion. Those of them which are in the state of elastic fluids must be excluded altogether; because in that particular state the particles, instead of being in the limit of cohesion, are actually repelled. In the earths, too, such of them at least as are found crystallized in a state of purity, the cohesion is very strong. Thus the sapphire or crystallized alumina, and rock crystal or crystallized silica, are always very hard, and exhibit a much stronger cohesion than limestone, or magnesian stones, which are composed of heterogeneous bodies. This remark, however, by no means applies to the metals; for in them the cohesion is very often increased considerably by alloying them together. Thus the cohesion of copper is doubled by alloying it with one-sixth of its weight of tin, though the cohesion of the tin is scarcely one-sixth of that of the copper.

The cohesion of metals is greatly increased by forging them and by drawing them out into wire. By this last operation gold, silver, and brass, have their

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\* See his *Theoria Philosophiæ Naturalis*, Part iii. Sect. 406. p. 185.

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cohesion nearly tripled; copper and iron more than doubled.

5. There are three states in which bodies exist exceedingly distinct from each other; the state of solids, of liquids, and of elastic fluids. In the two first states the particles cohere with more or less force; but the cohesion produces in them very different effects. In the first it prevents all relative motion among the particles themselves; in the second, this relative motion is left at full liberty. Hence in solid bodies the motion of one particle is followed by the motion of the whole mass; or if that is impossible, the cohesion is destroyed altogether. In liquids, on the contrary, the motion of one particle is not necessarily followed by that of the rest, neither does that motion destroy the cohesion. Boscovich has shewn, that solidity and fluidity are the consequence of the figure of the cohering particles. If that figure is such that the particles may change their position without altering their relative distances, the consequence must be fluidity; because in that case there is nothing to oppose the motion of any individual particle. This happens when the particles are spherical; but if the figure be such that the particles cannot change their position without altering their relative distances, the bodies which they compose must be solids, because all relative motion of an individual particle is opposed by the attractions and repulsions of all the surrounding particles; for every motion must bring the particle out of the former limit of cohesion. This happens when the particles have the figure of parallelopipeds, or any other figure except that of spheres.

This explanation is exceedingly ingenious; but it would not be an easy task to explain by means of it all

the phenomena of solidity and fluidity. How comes it, for instance, that the addition of a certain dose of caloric renders a body fluid which was before solid? If it be answered, that it acts by combining with the particles of the solid in such a manner as to render them spherical; how comes it, in that case, that gold and platinum, metals which are ductile and malleable, properties which indicate a kind of approach to fluidity, and of course to sphericity, in the particles of these metals—how comes it that they require so much more caloric to render them fluid than bismuth or sulphur, which are altogether brittle? We must rather consider fluidity as a kind of solution in caloric, analogous to the solution of salts in water. But this explanation, tho' it would do very well in many instances, would lead us in others to difficulties as great as those which we are endeavouring to avoid.

The cohesion of liquids is often very considerable. According to Sir Isaac Newton, it is nearly proportional to the density of the liquid. This holds pretty accurately in several instances: but it is not easy to ascertain the cohesion of a liquid with precision, because the particles slide upon each other, and the column of the liquid, whose cohesion we are measuring, always becomes smaller and smaller, till at last it consists only of a very small number of particles.

Viscid bodies have particles approaching to a spherical form; but deviating from it so far as to occasion a certain resistance to the relative motion of the particles.

Solid bodies are of two kinds: they may either resist all change of distance in their particles so strongly as not to be capable of compression or dilatation with-

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out a breach of cohesion; or they may admit of both to a certain degree with facility. The first of these constitutes hardness; the second constitutes softness, if the particles retain their new situation, or elasticity if they return again to their old position when the external force is removed\*. Ductility and malleability depend upon the same state as softness, only the particles require a greater force to make them change their situation and assume a new one.

Solution.

6. When a solid body is plunged into a liquid, if the particles of the liquid attract those of the solid with a greater force than these last particles attract each other, they are gradually carried off by the fluid, and combine with its particles, that is to say, the solid is gradually dissolved. Thus sugar is dissolved by water, and sulphur by oil. The particles of the solid thus dissolved are each of them surrounded and combined with a certain number of the particles of the liquid. Hence they must be arranged in the liquid in regular order, and at regular distances from each other. The greater number of particles thus dissolved by the liquid, the smaller is the affinity by which each of them is retained, because it is surrounded by a smaller number of particles of the liquid. But the greater must be the force with which these particles are attracted towards each other, and of course tend to form the solid again by cohesion; because the greater the number of the particles of the solid dissolved in the fluid, the nearer are they to each other.

Thus it appears that the affinity between the fluid and solid diminishes with the quantity dissolved; but that the tendency to cohesion increases with that quan-

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\* Boscovich, *Theoria Naturalis*, p. 199.



tity. Consequently if the solution be supposed to go on, these two opposite forces must at last balance one another. And whenever that happens, the liquid can dissolve no more of the solid. If it did, the particles of the solid would in part cohere, and form a new portion of the solid again. Whenever this happens, the fluid is said to be *saturated*. The saturation of a fluid then does not mean that its affinity for the solid is satisfied, but that it is not greater than the tendency of the combined particles to cohere. Now, when a liquid is saturated with a solid, if by any means we can abstract part of that liquid, the cohesive force of the particles of the solid must gain the superiority; and the consequence will be, that they will unite and form solid bodies anew, till their number be so much diminished, that their mutual attraction is again counterbalanced by the affinity of the liquid. Hence the reason that evaporation occasions the crystallization of those bodies which are held in solution by liquids.

7. These different solid bodies differ excessively from each other in their tendency to cohesion; and this difference can only be ascertained by experiment. Thus the tendency to cohesion, and the force of cohesion in silica, is so strong, that when it has been precipitated from a solution by evaporation, it cannot be dissolved again in the same liquid.

This tendency to cohesion, and the consequent insolubility of the compound, produce many of the most important phenomena of chemistry, as they occasion the various precipitations and decompositions which so often take place when different substances are mixed together. But this subject belongs more properly to the next Chapter, in which it will be necessary to point

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out the effect of cohesion as an antagonist to heterogeneous affinity. Let us proceed, therefore, to consider the forms which bodies assume when their particles have full liberty to unite themselves by cohesion.

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## SECT. II.

### OF CRYSTALLIZATION.

THE word *crystal* (*κρυσταλλος*), originally signified *ice*; but it was afterwards applied by the ancients to crystallized silica, or *rock crystal*; because, as Pliny informs us, they considered that body as nothing else than water congealed by the action of cold. Chemists afterwards applied the word to all transparent bodies of a regular shape; and at present it is employed to denote in general the regular figures which bodies assume when their particles have full liberty to combine according to the laws of cohesion. Now there are three ways by which they may be put into that situation, namely, solution, suspension, and fusion.

Crystals  
formed by

Solution,

1. Solution is the common method of crystallizing salts. They are dissolved in water: the water is slowly evaporated, the saline particles gradually approach each other, combine together, and form small crystals; which become constantly larger by the addition of other particles till at last they fall by their gravity to the bottom of the vessel. It ought to be remarked, however, that there are two kinds of solution, each of which pre-

sents different phenomena of crystallization. Some salts dissolve in very small proportions in cold water, but are very soluble in hot water; that is to say, water at the common temperature has little effect upon them, but water combined with caloric dissolves them readily. When hot water saturated with any of these salts cools, it becomes incapable of holding them in solution: the consequence of which is, that the saline particles gradually approach each other and crystallize. Sulphat of soda is a salt of this kind. To crystallize such salts nothing more is necessary than to saturate hot water with them, and set it by to cool. But were we to attempt to crystallize them by evaporating the hot water, we should not succeed; nothing would be procured but a shapeless mass. Many of the salts which follow this law of crystallization combine with a great deal of water; or, which is the same thing, many crystals formed in this manner contain a great deal of water of crystallization.

There are other salts again which are nearly equally soluble in hot and cold water; common salt for instance. It is evident that such salts cannot be crystallized by cooling; but they crystallize very well by evaporating their solution while hot. These salts generally contain but little water of crystallization.

2. It appears, too, that some substances are capable of assuming a crystalline form merely by having their particles suspended in water, without any regular solution; at least it is not easy, on any other supposition, to explain the crystallizations of carbonat of lime sometimes deposited by waters that run over quantities of that mineral.

Suspension,

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Fusion.

3. There are many substances, however, neither soluble in water, nor capable of being so minutely divided as to continue long suspended in that fluid; and which, notwithstanding, are capable of assuming a crystalline form. This is the case with the metals, with glass, and some other bodies. The method employed to crystallize them is *fusion*, which is a solution by means of caloric. By this method the particles are separated from one another; and if the cooling goes on gradually, they are at liberty to arrange themselves in regular crystals.

There are several bodies which it has been impossible hitherto to reduce to a regular crystallized form, either by these or any other method, owing chiefly, no doubt, to our ignorance of the laws of crystallization; for many of these bodies are found native in regular crystals. This is the case with carbon and alumina, and many earthy combinations.

Nature of  
crystalliza-  
tion.

4; The phenomena of crystallization seem to have attracted but little of the attention of the ancient philosophers. Their theory indeed, that the elements of bodies possess certain regular geometrical figures, may have been suggested by these phenomena; but we are ignorant of their having made any regular attempt to explain them. The schoolmen ascribed the regular figure of crystals to their substantial forms, without giving themselves much trouble about explaining the meaning of the term. This notion was attacked by Boyle; who proved, that crystals are formed by the mere aggregation of particles \*. But it still remained to explain,

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\* *Treatise on the Origin of Forms and Qualities.*



why that aggregation took place? and why the particles united in such a manner as to form regular figures?

The aggregation is evidently the consequence of that attractive force which has been examined in the last Section. But to explain the cause of the regular figures is a more difficult task. Newton has remarked, that the particles of bodies while in a state of solution, are arranged in the solvent in regular order and at regular distances; the consequence of which must be, that when the force of cohesion becomes sufficiently strong to separate them from the solvent, they will naturally combine in groups, composed of those particles which are nearest each other. Now all the particles of the same body must be supposed to have the same figure; and the combination of a determinate number of similar bodies must produce similar figures. Hauy has made it exceedingly probable that these integrant particles always combine in the same body in the same way, that is to say, that the same faces, or the same edges, always attach themselves together; but that these differ in different crystals. This can scarcely be accounted for, without supposing that the particles of bodies are endowed with a certain polarity which makes them attract one part of another particle and repel the other parts. This polarity would explain the regularity of crystallization; but it is itself inexplicable.

5. It has been observed, that those salts which crystallize upon cooling, do not assume a crystalline form so readily if they are allowed to cool in close vessels. If a saturated solution of sulphat of soda, for instance, in hot water, be put into a phial, corked up closely, and allowed to cool without being moved, no crystals are

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formed at all ; but the moment the glass is opened, the salt crystallizes with such rapidity that the whole of the solution in a manner becomes solid. This phenomenon has been explained by supposing that there is an affinity between the salt and caloric, and that while the caloric continues combined with it the salt does not crystallize; that the caloric does not leave the salt so readily when external air is not admitted, as glass receives it very slowly and parts with it very slowly. In short, the atmospherical air seems to be the agent employed to carry off the caloric; a task for which it is remarkably well fitted, on account of the change of density which it undergoes by every addition of caloric. This is confirmed by the quantity of caloric which always makes its appearance during these sudden crystallizations. This explanation might be put to the test of experiment, by putting two solutions of sulphat of soda in hot water in two similar vessels ; one of glass, the other of metal, and both closed in the same manner. If the salt contained in the metallic vessel crystallized, which ought to be the case on account of the great conducting power of metals, while that in the glass vessel remained liquid, this would be a confirmation of the theory, amounting almost to demonstration. On the contrary, if both solutions remained liquid, it would be a proof that the phenomenon was still incompletely understood.

Not only salts but water itself, which commonly crystallizes at  $32^{\circ}$ , may be made to exhibit the same phenomenon: it may be cooled much lower than  $32^{\circ}$  without freezing. This, as Dr Black has completely proved, depends entirely upon the retention of caloric.

6. If the figure of crystals depends upon the figure of their integrant particles, and upon the manner in which they combine, it is reasonable to suppose that the same particles, when at full liberty, will always combine in the same way, and consequently that the crystals of every particular body will be always the same. Nothing at first sight can appear farther from the truth than this. The different forms which the crystals of the same body assume are often very numerous, and exceedingly different from each other. Carbonat of lime, for instance, has been observed crystallized in no fewer than forty different forms, fluat of lime in eight different forms, and sulphat of lime in nearly an equal number.

All crystals have a primitive form.

But this inconsistency is not so great as might at first sight appear. Romé de Lisle has shown that every body susceptible of crystallization has a particular form which it most frequently assumes, or at least to which it most frequently approaches. Bergman has demonstrated, that this primitive form, as Haüy has called it, very often lies concealed in those very crystals which appear to deviate farthest from it. And Haüy has demonstrated, that all crystals either have this primitive form, or at least contain it as a nucleus within them; for it may be extracted out of all of them by a skilful mechanical division.

Happening to take up a hexangular prism of calcareous spar, or carbonat of lime, which had been detached from a group of the same kind of crystals, he observed that a small portion of the crystal was wanting, and that the fracture presented a very smooth surface. Let  $abcd$   $efgb$  (fig 12.) be the crystal; the fracture lay obliquely as the trapezium  $pstu$ , and made an angle of  $135^\circ$ ,

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both with the remainder of the base  $abcsph$  and with  $tuef$ , the remainder of the side  $inef$ . Observing that the segment  $psutin$  thus cut off had for its vertex  $in$ , one of the edges of the base  $abcnib$  of the prism, he attempted to detach a similar segment in the part to which the next edge  $cn$  belonged; employed for that purpose the blade of a knife, directed in the same degree of obliquity as the trapezium  $psut$ , and assisted by the strokes of a hammer. He could not succeed: But upon making the attempt upon the next edge  $bc$ , he detached another segment, precisely similar to the first, and which had for its vertex the edge  $bc$ . He could produce no effect on the next edge  $ab$ ; but from the next following,  $ab$ , he cut a segment similar to the other two. The sixth edge likewise proved refractory. He then went to the other base of the prism  $defgbr$ , and found, that the edges which admitted sections similar to the preceding ones were not the edges  $ef$ ,  $dr$ ,  $gk$ , corresponding with those which had been found divisible at the opposite base, but the intermediate edges  $de$ ,  $kr$ ,  $gf$ . The trapezium  $lqyv$  represents the section of the segment which had  $kr$  for its vertex. This section was evidently parallel to the section  $psut$ ; and the other four sections were also parallel two and two. These sections were, without doubt, the natural joinings of the layers of the crystal. And he easily succeeded in making others parallel to them, without its being possible for him to divide the crystal in any other direction. In this manner he detached layer after layer, approaching always nearer and nearer the axis of the prism, till at last the bases disappeared altogether, and the prism was converted into a solid  $OX$  (fig. 13.), terminated by twelve pentagons, parallel two and two; of



which those at the extremities, that is to say, ASRIO, IGEDO, BAODC at one end, and FKNPQ, MNPXU, ZQPXY at the other, were the results of mechanical division, and had their common vertices O, P situated at the entrance of the bases of the original prism. The six lateral pentagons RSUXY, ZYRIG, &c. were the remains of the six sides of the original prism.

By continuing sections parallel to the former ones, the lateral pentagons diminished in length; and at last the points R, G coinciding with the points Y, Z, the points S, R with the points U, Y, &c. there remained nothing of the lateral pentagons but the triangles YIZ, UXY, &c. (fig. 14.). By continuing the same sections, these triangles at last disappeared, and the prism was converted into the rhomboid *ae* (fig. 15.).

So unexpected a result induced him to make the same attempt upon more of these crystals; and he found that all of them could be reduced to similar rhomboids. He found also, that the crystals of other substances could be reduced in the same manner to certain primitive forms; always the same in the same substances, but every substance having its own peculiar form. The primitive form of fluat of lime, for instance, was an octahedron; of sulphat of barytes, a prism with rhomboidal bases; of felspar, an oblique angled parallelepiped, but not rhomboidal; of adamantine spar, a rhomboid, somewhat acute; of blende, a dodecahedron, with rhomboidal sides; and so on.

These primitive forms must depend upon the figure of the integrant particles composing these crystals, and upon the manner in which they combine with each other. Now by continuing the mechanical division of the crystal, by cutting off slices parallel to each of its

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 Integrant  
 particles of  
 three fi-  
 gures,

faces, we must at last reduce it to so small a size that it shall contain only a single integrant particle. Consequently this ultimate figure of the crystal must be the figure of the integrant particles of which it is composed. The mechanical division, indeed, cannot be continued so far, but it may be continued till it can be demonstrated that no subsequent division can alter its figure. Consequently it can be continued till the figure which it assumes is similar to that of its integrant particles.

Haüy has found, that the figure of the integrant particles of bodies, as far as experiment has gone, may be reduced to three; namely,

1. The parallelopiped, the simplest of the solids, whose faces are six in number, and parallel two and two.

2. The triangular prism, the simplest of prisms.

3. The tetrahedron, the simplest of pyramids. Even this small number of primitive forms if we consider the almost endless diversity of size, proportion, and density, to which particles of different bodies, though they have the same figure, may still be liable, will be found fully sufficient to account for all the differences in cohesion and heterogeneous affinity without having recourse to different absolute forces.

These integrant particles, when they unite to form the primitive crystals, do not always join together in the same way. Sometimes they unite by their faces, and at other times by their edges, leaving considerable vacuities between each. This explains why integrant particles, though they have the same form, may compose primitive crystals of different figures.

Mr Hauy has ascertained, that the primitive forms of crystals are six in number; namely,

1. The parallelopiped, which includes the cube, the rhomboid, and all solids terminated by six faces, parallel two and two.

2. The regular tetrahedron.

3. The octahedron with triangular faces.

4. The six-sided prism.

5. The dodecahedron, terminated by rhombs.

6. The dodecahedron, with isosceles triangular faces.

Each of these may be supposed to occur as the primitive form or the nucleus in a variety of bodies; but those only which are regular, as the cube and the octahedron, have hitherto been found in any considerable number.

But bodies, when crystallized, do not always appear in the primitive form; some of them indeed very seldom affect that form; and all of them have a certain latitude and a certain number of forms which they assume occasionally as well as the primitive form. Thus the primitive form of flint of lime is the octahedron; but that salt is often found crystallized in cubes, in rhomboidal dodecahedrons, and in other forms. All these different forms which a body assumes, the primitive excepted, have been denominated by Hauy *secondary forms*. Now what is the reason of this latitude in crystallizing? why do bodies assume so often these secondary forms?

7. To this it may be answered:

1st, That these secondary forms are sometimes owing to variations in the ingredients which compose the integrant particles of any particular body. Alum, for instance, crystallizes in octahedrons; but when a quan-

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Primitive crystalline forms, six,

Secondary crystals owing to

Differences in the composition;

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tity of alumina is added, it crystallizes in cubes; and when there is an excess of alumina, it does not crystallize at all. If the proportion of alumina varies between that which produces octahedrons and what produces cubic crystals, the crystals become figures with fourteen sides; six of which are parallel to those of the cube and eight to those of the octahedron; and according as the proportions approach nearer to those which form cubes or octahedrons, the crystals assume more or less of the form of cubes or octahedrons. What is still more, if a cubic crystal of alum be put into a solution that would afford octahedral crystals, it passes into an octahedron: and, on the other hand, an octahedral crystal put into a solution that would afford cubic crystals becomes itself a cube \*. Now, how difficult a matter it is to proportion the different ingredients with absolute exactness must appear evident to all.

In the sol-  
vents; and

2d, The secondary forms are sometimes owing to the solvent in which the crystals are formed. Thus if common salt be dissolved in water, and then crystallized, it assumes the form of cubes; but when crystallized in urine, it assumes the form not of cubes, but of regular octahedrons. On the other hand, muriat of ammonia, when crystallized in water, assumes the octahedral form, but in urine it crystallizes in cubes †.

3d, But even when the solvent is the same, and the proportion of ingredients, as far as can be ascertained, exactly the same, still there are a variety of secondary forms which usually make their appearance. These secondary forms have been happily explained by the

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\* Le Blanc, *Ann. de Chim.* xiv. 149.

† Fourcroy and Vauquelin, *Ibid.*



theory of crystallization, for which we are indebted to the sagacity of Mr Haüy ; a theory which, for its ingenuity, clearness, and importance, must ever rank high, and which must be considered as one of the greatest acquisitions which mineralogy and even chemistry have hitherto attained.

According to this theory, the additional matter which envelopes the primitive nucleus consists of thin slices or layers of particles laid one above another upon the faces of that nucleus; and each layer decreasing in size, in consequence of the abstraction of one or more rows of integrant particles from its edges or angles.

Let us suppose that ABFG (fig. 16.) is a cube composed of 729 small cubes : each of its sides will consist of 81 squares, being the external sides of as many cubic particles, which together constitute the cube. Upon ABCD, one of the sides of this cube, let us apply a square lamina, composed of cubes equal to those of which the primitive crystal consists, but which has on each side a row of cubes less than the outermost layer of the primitive cube. It will of course be composed of 49 cubes, 7 on each side; so that its lower base *onfg* (fig. 17.) will fall exactly on the square marked with the same letters in fig. 16.

Above this lamina let us apply a second *lm pu* (fig. 18.), composed of 25 cubes; it will be situated exactly above the square marked with the same letters (fig. 16.) Upon this second let us apply a third lamina *vx yz* (fig. 19.), consisting only of 9 cubes; so that its base shall rest upon the letters *vx yz* (fig. 16.) Lastly, on the middle square *r* let us place the small cube *r* (fig. 20.), which will represent the last lamina.

It is evident that by this process a quadrangular py-

To the different decrements of the crystalline laminae.

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ramid has been formed upon the face ABCD (fig. 16.), the base of which is this face, and the vertex the cube  $r$  (fig. 20.) By continuing the same operation on the other five sides of the cube, as many similar pyramids will be formed; which will envelope the cube on every side.

It is evident, however, that the sides of these pyramids will not form continued planes, but that, owing to the gradual diminution of the laminæ of the cubes which compose them, these sides will resemble the steps of a stair. We can suppose, however (what must certainly be the case), that the cubes of which the nucleus is formed are exceedingly small, almost imperceptible; that therefore a vast number of laminæ are required to form the pyramids, and consequently that the channels which they form are imperceptible. Now DCBE (fig. 21.) being the pyramid resting upon the face ABCD (fig. 16), and CBOG (fig. 21.) the pyramid applied to the next face BCGH (fig. 16.), if we consider that every thing is uniform from E to O (fig. 21.) in the manner in which the edges of the *laminæ of superposition* (as the Abbé Haüy calls the laminæ which compose the pyramids) mutually project beyond each other, it will readily be conceived that the face CEB of the first pyramid ought to be exactly in the same plane with the face COB of the adjacent pyramid; and that therefore the two faces together will form one rhomb ECOB. But all the sides of the six pyramids amount to 24 triangles similar to CEB; consequently they will form 12 rhombs, and the figure of the whole crystal will be a dodecahedron.

Thus we see that a body which has the cube for the primitive form of its crystals, may have a dodecahedron

for its secondary form. The formation of secondary crystals, by the superposition of laminæ gradually decreasing in size, was first pointed out by Bergman. But Haüy has carried the subject much farther: He has not only ascertained all the different ways by which these decrements of the laminæ may take place, but pointed out the method of calculating all the possible variety of secondary forms which can result from a given primitive form; and consequently of ascertaining whether or not any given crystal can be the secondary form of a given species.

The decrements of the laminæ which cover the primitive nucleus in secondary crystals are of four kinds.

1. *Decrements on the edges*; that is, on the edges of the slices which correspond with the edges of the primitive nucleus.

These of  
four kinds.

2. *Decrements on the angles*; that is to say, parallel to the diagonals of the faces of the primitive nucleus.

3. *Intermediate decrements*; that is to say, parallel to lines situated obliquely between the diagonals and edges of the faces of the primitive nucleus.

4. *Mixed decrements*. In these the superincumbent slices, instead of having only the thickness of one integrant particle, have the thickness of two or more integrant particles; and the decrement, whether parallel to the edges or angles, consists not of the abstraction of one row of particles, but of two or more. Haüy denotes these decrements by fractions, in which the numerator indicates the number of rows of particles which constitutes the decrement, and the denominator represents the thickness of the laminæ. Thus  $\frac{2}{3}$  denotes laminæ of the thickness of three integrant particles, decreasing by two rows of particles.

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## 1. Decrements on edges.

An example of the first law of decrement, or of *decrement on the edges*, has been given above in conversion of the cubic nucleus to a rhomboidal dodecahedron. In that example the decrement consisted of one row of particles, and it took place on all the edges. But these decrements may be more rapid; instead of one, they may consist of two, three, four, or more rows: and instead of taking place on all the edges, they may be confined to one or two of them, while no decrement at all takes place on the others. Each of these different modifications must produce a different secondary crystal. Besides this, the laminæ may cease to be added before they have reached their smallest possible size; the consequence of which must be a different secondary form. Thus, in the example given above, if the superposition of laminæ had ceased before the pyramids were completed, the crystal would have consisted of 18 faces, 6 squares parallel to the faces of the primitive nucleus, and 12 hexahedrons parallel to the faces of the secondary dodecahedron. This is the figure of the borat of lime-and-magnesia found at Luneburg.

## 2. Decrements on the angles.

The second law in which the decrement is on the angles, or parallel to the diagonals of the faces of the primitive nucleus, will be understood from the following example: Let it be proposed to construct around the cube ABGF (fig. 22.), considered as a nucleus, a secondary solid, in which the laminæ of superposition shall decrease on all sides by single rows of cubes, but in a direction parallel to the diagonals. Let ABCD (fig. 23.), the superior base of the nucleus, be divided into 81 squares, representing the faces of the small cubes of which it is composed. Fig. 24. represents the superior surface of the first lamina of superposition;



which must be placed above ABCD (fig. 23.) in such a manner, that the points  $a', b', c', d'$ , (fig. 24.) answer to the points  $a, b, c, d$ , (fig. 23.) By this disposition, the squares  $Aa, Bb, Cc, Dd$ , (fig. 23.) which compose the four outermost rows of squares parallel to the diagonals AC, BD, remain uncovered. It is evident also, that the borders QV, ON, IL, GF, (fig. 24.) project by one range beyond the borders AB, AD, CD, BC, (fig. 23.), which is necessary, that the nucleus may be enveloped towards these edges: For if this were not the case, re-entering angles would be formed towards the parts AB, BC, CD, DA of the crystal; which angles appear to be excluded by the laws which determine the formation of simple crystals, or, which comes to the same thing, no such angles are ever observed in any crystal. The solid must increase, then, in those parts to which the decrement does not extend. But as this decrement is alone sufficient to determine the form of the secondary crystal, we may set aside all the other variations which intervene only in a subsidiary manner, except when it is wished, as in the present case, to construct artificially a solid representation of a crystal, and to exhibit all the details which relate to its structure.

The superior face of the second lamina will be  $A'G' L'K'$  (fig. 25.) It must be placed so that the points  $a'', b'', c'', d''$  correspond to the points  $a', b', c', d'$ , (fig. 24.), which will leave uncovered a second row of cubes at each angle, parallel to the diagonals AC and BD. The solid still increases towards the sides. The large faces of the laminæ of superposition, which in fig. 24. were octagons, in fig. 25. arrive at that of a square; and when they pass that term they decrease on all sides;

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so that the next lamina has for its superior face the square  $B'M'L'S'$  (fig. 26.), less by one range in every direction than the preceding lamina (fig. 25.) This square must be placed so that the points  $e', f', g', b'$ , (fig. 26.) correspond to the points  $e, f, g, b$ , (fig. 25.) Figures 27, 28, 29, and 30, represent the four laminæ which ought to rise successively above the preceding; the manner of placing them being pointed out by corresponding letters, as was done with respect to the three first laminæ. The last lamina  $\alpha'$  (fig. 31.) is a single cube, which ought to be placed upon the square  $\alpha$  (fig. 30.)

The laminæ of superposition, thus applied upon the side ABCD (fig. 23.), evidently produce four faces, which correspond to the points A, B, C, D, and form a pyramid. These faces, having been formed by laminæ, which began by increasing, and afterwards decreased, must be quadrilaterals of the figure represented in fig. 32.; in which the inferior angle C is the same point with the angle C of the nucleus (fig. 22. and 23.); and the diagonal LQ represents  $L'G'$  of the lamina  $A'G'L'K'$  (fig. 25.) And as the number of laminæ composing the triangle LQC (fig. 32.) is much smaller than that of the laminæ forming the triangle ZLQ, it is evident that the latter triangle will have a much greater height than the former.

The surface, then, of the secondary crystal thus produced, must evidently consist of 24 quadrilaterals (for pyramids are raised on the other 5 sides of the primary cube exactly in the same manner, disposed 3 and 3 around each solid angle of the nucleus. But in consequence of the decrement by one range, the three quadrilaterals which belong to each solid angle, as C (fig.

22.), will be in the same plane, and will form an equilateral triangle ZIN (fig 33.) The 24 quadrilaterals, then, will produce 8 equilateral triangles; and consequently the secondary crystal will be a regular octahedron. This is the structure of the octahedral sulphuret of lead and of muriat of soda.

The third law is occasioned by the abstraction of double, triple, &c. particles. Fig. 34 exhibits an instance of the subtractions in question; and it is seen that the *moleculæ* which compose the range represented by that figure are assorted in such a manner as if of two there were formed only one; so that we need only to conceive the crystal composed of parallelopipedons having their bases equal to the small rectangles *abcd*, *cdfg*, *bgil*, &c. to reduce this case under that of the common decrements on the angles.

This particular decrement, as well as the fourth law, which requires no farther explanation, is uncommon. Indeed Haüy has only met with mixed decrements in some metallic crystals.

These different laws of decrement account for all the different forms of secondary crystals. But in order to see the vast number of secondary forms which may result from them, it is necessary to attend to the different modifications which result from their acting separately or together. These modifications may be reduced to seven

1. The decrements take place sometimes on all the edges, or all the angles, at once.
2. Sometimes only on certain edges, or certain angles
3. Sometimes they are uniform, and consist of one, two, or more rows.

Modifications to which these decrements are subject.

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4. Sometimes they vary from one edge to another, or from one angle to another.

5. Sometimes decrements on the edges and angles take place at the same time.

6. Sometimes the same edge or angle is subjected successively to different laws of decrement.

7. Sometimes the secondary crystal has faces parallel to those of the primitive nucleus, from the superposition of laminæ not going beyond a certain extent.

Hence Mr Haüy has divided secondary forms into two kinds, namely, *simple* and *compound*. Simple secondary crystals are those which result from a single law of decrement, and which entirely conceal the primitive nucleus. Compound secondary crystals are those which result from several laws of decrement at once, or from a single law which has not reached its limit, and which of course has left in the secondary crystal faces parallel to those of the primitive nucleus.

“ If amidst this diversity of laws (observes Mr Haüy), sometimes insulated, sometimes united by combinations more or less complex, the number of the ranges subtracted were itself extremely variable; for example, were these decrements by 12, 20, 30, or 40 ranges, or more, as might absolutely be possible, the multitude of the forms which might exist in each kind of mineral would be immense, and exceed what could be imagined. But the power which affects the subtractions seems to have a very limited action. These subtractions, for the most part, take place by one or two ranges of molecules. I have found none which exceeded four ranges, except in a variety of calcareous spar, forming part of the collection of C. Gillet Laumont, the structure of which depends on a decrement by six ranges; so that



if there exist laws which exceed the decrements by four ranges, there is reason to believe that they rarely take place in nature. Yet, notwithstanding these narrow limits by which the laws of crystallization are circumscribed. I have found, by confining myself to two of the simplest laws, that is to say, those which produce subtractions by one or two ranges, that calcareous spar is susceptible of 2044 different forms: a number which exceeds more than 50 times that of the forms already known; and if we admit into the combination decrements by three and four ranges, calculation will give 8,388,604 possible forms in regard to the same substance. This number may be still very much augmented in consequence of decrements either mixed or intermediary.

The striæ remarked on the surface of a multitude of crystals afford a new proof in favour of theory, as they always have directions parallel to the projecting edges of the laminae of superposition, which mutually go beyond each other, unless they arise from some particular want of regularity. Not that the inequalities resulting from the decrements must be always sensible, supposing the form of the crystals had always that degree of finishing of which it is susceptible; for, on account of the extreme minuteness of the molecules, the surface would appear of a beautiful polish, and the striæ would elude our senses. There are therefore secondary crystals where they are not at all observed, while they are very visible in other crystals of the same nature and form. In the latter case, the action of the causes which produce crystallization not having fully enjoyed all the conditions necessary for perfecting that so delicate operation of nature, there have been starts and interruptions

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in their progress; so that, the law of continuity not having been exactly observed, there have remained on the surface of the crystal vacancies apparent to our eyes. These small deviations are attended with this advantage, that they point out the direction according to which the striæ are arranged in lines on the perfect forms where they escape our organs, and thus contribute to unfold to us the real mechanism of the structure.

The small vacuities which the edges of the laminæ of superposition leave on the surface of even the most perfect secondary crystals, by their re-entering and salient angles, thus afford a satisfactory solution of the difficulty a little before mentioned; which is, that the fragments obtained by division, the external sides of which form part of the faces of the secondary crystal, are not like those drawn from the interior part. For this diversity, which is only apparent, arises from the sides in question being composed of a multitude of small planes, really inclined to one another, but which, on account of their smallness, present the appearance of one plane; so that if the division could reach its utmost bounds, all these fragments would be resolved into molecules similar to each other, and to those situated towards the centre.

The fecundity of the laws on which the variations of crystalline forms depend, is not confined to the producing of a multitude of very different forms with the same molecules. It often happens also, that molecules of different figures arrange themselves in such a manner as gives rise to like polyhedra in different kinds of minerals. Thus the dodecahedron with rhombuses for its planes, which we obtained by combining cubic mole-

cules, exists in the granite with a structure composed of small tetrahedra, having isosceles triangular faces; and I have found it in sparry fluor (*fluat of lime*), where there is also an assemblage of tetrahedra, but regular; that is to say, the faces of which are equilateral triangles. Nay more, it is possible that similar molecules may produce the same crystalline form by different laws of decrement. In short, calculation has conducted me to another result, which appeared to me still more remarkable, which is, that, in consequence of a simple law of decrement, there may exist a crystal which externally has a perfect resemblance to the nucleus, that is to say, to a solid that does not arise from any law of decrement\*."

SUCH is a general view of Haüy's theory of crystallization, which has led already to several very important discoveries in mineralogy, and may be expected to lead to still more important ones hereafter. The evidence for its truth is the complete manner in which it explains the phenomena, and the exact coincidence of matter of fact in every instance, with the result of calculation. But as it cannot be shewn that the secondary forms are actually crystallized according to the theory, we must consider it in the light of a mathematical hypothesis; an hypothesis, however, of very great importance, because it serves to link together a vast number of otherwise unconnected facts; because it enables us to subject all the forms of crystals to calculation; and because it puts it in our power to ascertain the nature of a body with the utmost certainty, from an accu-

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\* *Ann. de Chim.* xvii. 225.

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rate examination of the figure of its crystals. Such hypotheses may be considered as the clues which lead us through the otherwise impenetrable mazes of error, and conduct us at last, though after a tedious journey, to the goal of certainty and truth.

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## CHAP. III.

## OF HETEROGENEOUS AFFINITY.

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HETEROGENEOUS AFFINITY differs from cohesion merely in being confined to heterogeneous particles. It is usually known by the appellation of *chemical affinity*, and has hitherto almost exclusively occupied the attention of chemists, on the supposition that it is exclusively the cause of all the compositions and decompositions with which they are conversant; though in fact its influence is neither more extensive nor more important than that of cohesion. Indeed the two powers are so intimately connected, that their actions are very seldom exhibited separately. In treating of heterogeneous affinity, it is necessary to consider, 1. How heterogeneous particles combine; 2. In what proportions they are capable of combining; 3. The force with which they combine; and, 4. What takes place when a variety of heterogeneous particles are made to act upon each other at the same time. These topics will form the subject of the four following Sections.



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SECT. I.

## OF COMBINATION.

I. WHETHER there exists a reciprocal affinity between every species of the particles of bodies, is a point which cannot easily be determined, though it is certainly very probable that there does. But as the particles of bodies are usually found cohering together in masses, it is evident that no heterogeneous bodies can combine unless their affinity for each other be stronger than the cohesive force which unites the respective particles of each. Now, whenever two bodies constantly refuse to combine, in whatever situation we place them, we say that they have *no* affinity for each other; meaning merely, that their affinity is not so great as to produce combination. Thus we say that there is no affinity between oil and water, because these two liquids refuse to combine together; yet when oil is united with alkali, and in the state of soap, it dissolves in water;—a proof that there does exist an affinity between water and oil, tho' not strong enough to produce combination. We say also, that there is no affinity between azot and lime, because azotic gas cannot be combined with that earth: yet nitric acid dissolves lime readily; which shews us that the refusal of lime and azotic gas to combine is not the consequence of the want of an affinity between these two bodies, but of some other cause.

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Bodies to  
be combin-  
ed; either  
insulated

2. We may present a body to another with which it is capable of combining in two different states; either insulated or already combined with some other body. Thus we may present lime to nitric acid, either in the state of pure lime, or combined with carbonic acid, and consequently in the state of a carbonat.

In the first case the affinity is opposed by the cohesion, and combination does not take place unless that force can be overcome. Hence the reason that combination seldom succeeds well, unless some of the bodies to be combined be fluid, or be assisted by heat, which has the property of diminishing the force of cohesion. Indeed there are not wanting numerous instances of solid bodies combining together without the assistance of heat; but they are always bodies which have the property of becoming liquid in the act of combination. Thus common salt and snow, muriat of lime and snow, &c. combine rapidly when mixed, and are converted into liquids.

It is to the force of cohesion that the difficulty of dissolving the diamond, the sapphyr, and many other natural bodies is to be ascribed, though composed of ingredients very readily acted on by solvents when their cohesive force is sufficiently diminished. If pure alumina be formed into a paste, and heated sufficiently, it becomes so hard that no acid can act upon it; yet its nature is not in the least changed: by proper trituration it may be again rendered soluble; and when precipitated from this new solution it has recovered all its original properties. The effect of the fire, then, was merely to increase the cohesion, by separating all the water, and allowing the particles to approach nearer each other.

3. Even when the cohesive force of the particles to

be combined is not very great, it may be still sufficient to prevent combination from taking place, provided the other body can only approach it in a very small mass. Hence the reason that carbonic acid gas, and other elastic fluids, have scarcely any action on the greater number of bodies, though they combine with them readily when the force of cohesion presents no opposition. Thus the oxygen of the atmosphere does not combine with sulphur in its natural state, though it unites with it readily when the sulphur is combined with hydrogen and potass, bodies which diminish its cohesion very considerably, or when it is converted into its integrant particles by the action of heat.

4. In the second case, or when the body presented to be combined with another is already in combination with some other body, it does not altogether leave the old body and combine with the new, but it is divided between them in proportion to the mass and the affinity of these bodies. Thus when lime, already in combination with phosphoric acid, is presented to sulphuric acid, it does not altogether leave the phosphoric to combine with the sulphuric acid, but it divides itself between these two acids, part combining with the one and part with the other, according to the respective quantities of each of these acids, and the strength of their affinity for the lime. This important point has been lately put in a very clear light by Mr Berthollet. Chemists had formerly in a great measure overlooked the modification produced on the action of heterogeneous bodies on each other by the different proportions of each; supposing that in all cases a substance A, which has a stronger affinity for C than B has, is capable of taking C altogether from B, provided it be added in

Or previously combined;

And then they are parted between the two acting bodies.

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sufficient quantity, how great soever the proportion of B exceeds that of A. Several exceptions, indeed, had been pointed out to this general law. Thus Cavendish ascertained, that lime-water is incapable of depriving air completely of carbonic acid. But Berthollet has demonstrated, that this pretended law never holds; that no substance whatever is capable of depriving another of the whole of a third, with which it is combined, except in particular circumstances, however strong its affinity for that third may be, and in how great a proportion soever it be added. Thus no proportion of lime whatever is capable of depriving the carbonat of potass of the whole of its acid. Neither does sulphuric acid decompose phosphat of lime completely, nor ammonia sulphat of alumina, nor potass sulphat of magnesia.

In short, it may be considered as a general law in chemistry, that the smaller the proportion of a body in combination with a given quantity of another body is, with the greater energy is it retained; so that at last the force of its affinity becomes stronger than any direct force that can be applied to separate it. Hence the impossibility of depriving sulphuric acid and several other bodies completely of water.

Bodies act  
in propor-  
tion to  
their mass,

Berthollet has shown also, that every body, how weak soever its affinity for another may be, is capable of abstracting part of that other from a third, how strong soever the affinity of that third is, provided it be applied in sufficient quantity. Thus potass is capable of abstracting part of the acid from sulphat of barytes, from oxalat of lime, phosphat of lime, and carbonat of lime: soda and lime abstract part of the acid from sulphat of potass, and nitric acid abstracts part of the base from oxalat of lime. Hence it follows that substances



are capable of decomposing each other reciprocally, provided they be added respectively in the proper quantity. Indeed this was known formerly to be the case, though it had not been considered as a general law till Berthollet drew the attention of chemists to it. Sulphuric acid decomposes nitrat of potass altogether by the assistance of heat. The nitric acid is driven off, and there remains behind sulphat of potass with an excess of acid. On the other hand, if nitric acid be poured into sulphat of potass in sufficient quantity, it takes a part of the base from the sulphuric acid. In the same manner phosphoric acid decomposes muriat of lead, and muriatic acid on the other hand decomposes phosphat of lead.

This reciprocal decomposition follows as a consequence from the nature of affinity. For if the affinity of one particle for another be an absolute force (supposing the distance, figure, and density constant), it certainly ought to follow that this force must be increased by the number of the attracting particles. If a particle A attract a particle B with a force  $= x$ , two particles A concurring together ought certainly to attract with a force  $= 2x$ , or at least with a force  $= y > x$ . Hence we see that the aggregate force of attraction ought to increase with the aggregate number of particles.

But this increase is not sufficient to explain the cause of decomposition. For undoubtedly, how much soever we suppose the attraction of a body A for another body C, to exceed the attraction of B already in combination with C, the addition of A, in how large a quantity soever, cannot be conceived to destroy the combination of B with C, unless some other cause intervene. The attraction between B and C cannot be annihilated, though it may be considerably diminished; it must

Decomposition explained.

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therefore be sufficient to keep the two bodies still united, notwithstanding the presence of A. A, no doubt, will also combine with C; the consequence of which would be a new compound, into which all the three bodies equally enter. This, indeed, must always happen when different bodies are mixed together, whatever their affinities for each other may be, unless some force or other intervene to determine the exclusion of some particular bodies. Thus, if the particles A and C, (supposing them numerous) have not only a strong affinity for each other, but also a strong force of cohesion, which leads the combined particles  $A + C$  to unite together and to form masses of sensible magnitude, the particles B may be excluded from these masses either totally or partially, according to their nature, while the masses themselves, becoming too heavy to remain suspended in a fluid, precipitate to the bottom. Hence the reason that barytes precipitates sulphuric acid completely from most of its combinations, and that muriatic acid has the same effect upon silver. Again, if the particles B are elastic, the addition of A, by weakening the force by which they are retained, conspires with this elasticity; the consequence of which may be, that B may fly off altogether, and leave A and C in combination. Hence the reason that sulphuric acid separates carbonic acid from all its combinations.

The presence of an elastic body, like carbonic acid, constitutes an exception to the general rule, that, other things being equal, the affinities of bodies are as their masses: for the elastic body making its escape constantly as it is disengaged, cannot possibly act by its mass.

The presence of an absolutely insoluble body, if

there be any such, must constitute an exception to both the general rules of Berthollet: For the addition of a body A, which forms an insoluble compound with C, may decompose completely the compound B + C. A and B combining, and forming an insoluble aggregate, must precipitate completely to the bottom. Hence barytes leaves no sensible quantity of sulphuric acid when dropt into a solution containing that acid; and muriatic acid in the same circumstances leaves no sensible quantity of silver. In this case, too, the body A must act independently of its mass; because separating almost instantaneously from the solution, the mass of B, however great, cannot oppose its action.

These remarks are sufficient to give us some notion of the manner in which bodies combine together. Let us now consider the *proportions* in which they are capable of combining.

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## SECT. II.

### OF SATURATION.

THE word SATURATION, like most other technical terms introduced into chemistry before the science had acquired much precision, has been used with a great deal of latitude, being sometimes taken in one sense and sometimes in another. But in order to be understood, it is necessary to use the word with some degree of precision: for that reason I shall, in this Section, confine it to that particular sense which seems best adapted to it.

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Saturation  
explained.

1. If we make the attempt, we shall find that water will not dissolve any quantity of salt that we please. At the temperature of  $60^{\circ}$ , it dissolves only 0.354 parts of its weight of salt; and if more salt than this be added, it remains in the water undissolved. When water has dissolved as much salt as possible, it is said to be *saturated* with salt. This sense is at least analogous to the original meaning of the word, and is that to which I mean to restrict it in this Section. Whenever, then, a substance A refuses to combine with an additional quantity of another body B, we may say that it is saturated with B. The cause of this refusal of the water to dissolve any more salt has been indicated in the preceding Chapter. It takes place whenever the affinity of the water and salt is balanced by the cohesion of the particles of the salt, and therefore indicates that these two forces are equal.

In the same manner water, after having absorbed a certain quantity of carbonic acid gas, refuses to absorb any more. We may indeed pass carbonic acid gas thro' water in this state, but it makes its escape unaltered. Water which refuses to absorb carbonic acid gas is *saturated* with that acid. This saturation takes place when the affinity between the gas and the water is balanced by the elasticity of the gas, and indicates of course that these two forces are equal.

Consists in  
the balan-  
cing of two  
forces.

In these two instances the saturation is occasioned by opposite causes. The salt refuses to dissolve in the water when the *cohesion* of its particles equals its affinity for the water; the carbonic acid gas, when the *repulsion* of its particles equals its affinity for water. In the first case, it is the attractive force of cohesion which opposes farther solution; in the second case, it is the



repulsive force of elasticity. Hence the different methods which must be followed to diminish these forces, and enable the water to dissolve a greater proportion of these respective bodies. Heat, by diminishing the force of cohesion, enables water to dissolve a greater proportion of saline bodies. Accordingly we find that in most cases hot water dissolves more salt than cold water. Common salt is almost the only exception to this general law. On the other hand, cold, by diminishing the elasticity, or at least the expansibility of gaseous bodies, enables water to dissolve a greater proportion of them. Thus the colder the water is, the greater a proportion of carbonic acid is it capable of dissolving. The freezing point of water limits this increase of solubility, because at that point the cohesive force of the particles of water becomes so great as to cause them to cohere, to the exclusion of those bodies with which they were formerly combined. Hence the reason that most bodies separate from water when it freezes. But they generally retard the freezing considerably, by opposing with all the strength of their affinity the cohesion of the water. The consequence is, that the freezing point of water, when it holds bodies in solution, is lower than the freezing point of pure water. A table of the freezing points of different saline solutions would be a pretty accurate indication of the affinity of the different salts for water: for the affinity of each salt is of course proportional to the degree of cold at which it separates from the water, that is, to the freezing point of the solution.

In this sense of the word *saturation*, which is certainly the only one that it ought to bear, it may be said with propriety that there are certain bodies which can-

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not be saturated by others. Thus water is capable of combining with any quantity whatever of sulphuric acid, nitric acid, and alcohol; and all bodies seem capable of combining with almost any quantity whatever of caloric. Several of the metals, too, are capable of combining with any quantity whatever of some other metals. In general, it may be said that those bodies called *solvents* are capable of combining in any quantity with the substances which they hold in solution. Thus water may be added in any quantity, however great, to the acids, and to the greater number of salts.

Neutralization

2. If we take a given quantity of sulphuric acid diluted with water, and add to it slowly the solution of soda by little at a time, and examine the mixture after every addition, we shall find that for a considerable time it will exhibit the properties of an acid. reddening vegetable blues, and having a taste perceptibly sour: but these acid properties gradually diminish after every addition of the alkaline solution, and at last disappear altogether. If we still continue to add the soda, the mixture gradually acquires alkaline properties, converting vegetable blues to green, and manifesting an urinous taste. These properties become stronger and stronger the greater the quantity of the soda is which is added. Thus it appears that when sulphuric acid and soda are mixed together, the properties either of the one or the other preponderate according to the proportions of each; but that there are certain proportions, according to which, when they are combined, they mutually destroy or disguise the properties of each other, so that neither predominates, or rather so that both disappear.

When substances thus mutually disguise each others properties, they are said to *neutralize* one another.

This property is common to a great number of bodies ; but it manifests itself most strongly, and was first observed, in the acids, alkalies, and earths. Hence the salts which are combinations of these different bodies received long ago the name of *neutral salts*. When bodies are combined in the proportion which produces neutralization, they are often said to be *saturated* ; but in this case the term is used improperly. It would be much better to confine the word *saturation* to the meaning assigned to it in the beginning of this Section, and to employ the term *neutralization* to denote the state in which the peculiar properties of the component parts mutually disappear ; for very frequently neutralization and saturation by no means coincide. Thus in *tartrite of potass* the acid and alkali neutralize each other ; yet it cannot be said that the potass is saturated ; for it is still capable of combining with more tartarous acid, and of forming super-tartrite of potass, a compound in which the ingredients do not neutralize each other ; for the salt has manifestly a preponderance of the properties of the acid.

When two substances neutralize each other, it is not easy to avoid supposing that they are either combined particle to particle, or nearly so. They must at least be combined in such a manner, that the particles of each are distributed everywhere in such equal proportions, that an equal number of both is applied to all bodies in which the compound acts ; or rather such a number of each, that its action upon all bodies is exactly equal to the effect of the other. The consequence of this must be, that both of them will act at the same time with equal energy upon every body which is exposed to their action. Hence, as far as their actions are opposite, they

Owing to  
an equality  
of affinity.

## Book III.

will mutually destroy each other; and, as far as they are not exactly opposite, they will produce a compound effect different from what would be produced by either singly; just as the mixture of two rays of light produces a colour different from the colour produced by each separately.

When bodies neutralize each other, they must be considered as in the most perfect state of combination possible, as they exactly balance each other. Consequently if a body A neutralizes a body B, the two are united in such proportions that the absolute force of the affinity of A for B is equal to that of B for A.

3. A question still remains to be resolved concerning the proportion in which bodies combine, which is attended with very considerable difficulty: Are bodies capable of combining with each other indefinitely, or do they only combine with each other in certain determinate proportions? The observations already made may seem to decide in favour of the first of these suppositions; but let us consider the subject a little more precisely.

Bodies only unite in certain proportions.

Let us suppose two bodies,  $a$  and  $b$ , to have an affinity for each other. Let us take one particle of  $a$  and combine it with as many particles of  $b$  as can approach within  $a$ 's sphere of affinity. It is clear that in this case  $a$  is absolutely saturated with  $b$ , and cannot possibly combine with any more particles of that body. Let us call the new compound  $a + x b$ . If the particles of  $b$  have a cohesive force, it is very possible that they may combine indefinitely with the compound  $a + x b$ ; but this combination cannot with propriety be considered as the union of more particles of  $b$  with  $a$ ; it would have taken place if  $a$  had not been present



at all, and must be ascribed entirely to the cohesion of the particles of  $b$ . Now if, instead of one particle of  $a$ , we suppose two or a thousand, the case will remain the same. Each particle may combine with as many particles of  $b$  as can come within the sphere of its attraction; but all additions of  $b$  beyond that must be ascribed entirely to the cohesion of the particles of  $b$ . Thus if  $a$  remains constant, we see that it can only combine with a finite portion of  $b$ ; consequently in those cases where saturation is impossible, the new doses of the solvent must be considered as combining merely with the solvent, and not with the body held in solution.

The same observation holds, if we suppose  $b$  constant and  $a$  variable. Indeed if we were to consider the reciprocal attractions of the particles of both bodies, and the spheres of attraction which surround every particle, it would be an extremely difficult matter to form any adequate notion of the manner in which they combine and act upon each other. But it is easy to see in general, that if the particles of a body  $a$  remain constant, they can only combine with a limited number of particles of another body  $b$ , because only a limited number can come within the spheres of their attraction.

Thus we see, that, strictly speaking, a given body  $a$  cannot combine with a body  $b$  beyond a certain proportion. But is there a limit on the other side? Can  $a$  combine with any quantity of  $b$ , however small, provided it be within the maximum? or is it necessary that, before any combination can take place, a certain definite proportion of  $b$  must be present? What is the minimum of  $b$  that can combine with a given portion of  $a$ ?

There is a maximum and minimum beyond which they cannot pass,

## Book III.

It is evident that if  $a$  has an affinity for  $b$ , one particle of each must be capable of combining together; at least nothing can be conceived to hinder them. But this does not answer the question; for we must suppose a considerable number of particles of  $a$  present. Let us then make  $x a =$  number of particles of  $a$ , which can approach within the sphere of attraction of a particle of  $b$ , and  $y x a =$  quantity of  $a$  present; it is evident from what has been said before, that  $y b$  is the minimum which is capable of combining with  $y x a$ . If less be added, part of  $a$  will remain combined only by cohesion. If this cohesion does not exist, then it is impossible that  $a$  and  $b$  can remain in combination in any proportion less than  $y x a$  and  $y b$ . Accordingly in water, where the component parts are elastic fluids, we find them always united in one determinate proportion. In this compound the maximum and minimum coincide apparently: We are not yet far enough advanced in our notions of affinity to say why. And in the metallic oxides, where one of the component parts is an elastic fluid, the minimum as well as the maximum consists of a precise proportion of oxygen.

Thus it appears, that in all combinations there are two precise limits, a minimum and a maximum, beyond which the component parts can never pass. It remains still for us to consider whether they can combine in any proportion within these limits. For instance, if the minimum of oxygen capable of combining with iron be 0.25, and the maximum 0.48, the question to be decided is, Can iron combine with any proportion whatever of oxygen between 0.25 and 0.48? or can it only combine with certain determinate proportions, such as 0.30 or 0.40?

When we consider the matter abstractedly, we can perceive nothing to prevent this combination of bodies in any proportion whatever within the limits of their maxima and minima; though it must be acknowledged that it would be exceedingly difficult to form any adequate notion of the manner in which they are combined in these circumstances. This indefinite combination seems formerly to have been considered as an axiom by chemists. It was abandoned, perhaps with too much facility, in consequence, chiefly, of the experiments of Lavoisier; but the opinion has lately been revived again, and supported with much ingenuity by Berthollet. Let us consult experience, which is alone capable of deciding the point: for our notions of affinity are still too imperfect and confused to warrant any deductions from abstract reasoning.

Chap. III.

Whether they combine indefinitely within these limits.

Now, as far as experience has gone, substances, if we attend only to the proportions in which they combine with each other, may be arranged under four classes.

1. Some seem to combine in any proportion whatever between the maxima and minima.
2. Some combine only in certain determinate proportions between the maxima and minima.
3. Some combine only in the proportions which constitute the maxima and minima.
4. In some the maximum and minimum coincide, so that they are capable of combining only in one determinate proportion. Let us consider each of these classes a little.

The *first* class, strictly speaking, scarcely includes any bodies except those which are incapable of saturation, and which therefore have a minimum but no vi-

## Book III.

sible maximum. Thus water is capable of combining with common salt in any proportion whatever beyond the minimum capable of holding the salt in solution. It holds also with all substances which are in solution, and which remain in solution, both at the maximum and minimum of combination. Thus the acids are capable of combining with alkalies, and with those earths which form soluble salts in any proportion below saturation.

To the *second* class belong almost all combinations of oxygen with other bodies. Thus all the simple combustibles except hydrogen are always found combined with oxygen in certain determinate proportions, and can only be combined artificially in these proportions. Thus we have

1. Sulphur	{	Oxide of sulphur,
	{	Sulphurous acid,
	{	Sulphuric acid.
2. Phosphorus	{	Oxide of phosphorus,
	{	Phosphorous acid,
	{	Phosphoric acid.
3. Carbon	{	Charcoal,
	{	Oxide of carbon,
	{	Carbonic acid.
4. Azot . . . . .	{	Air,
	{	Oxide of azot,
	{	Nitrous gas,
	{	Nitric acid.

With respect to the metallic oxides, our knowledge is not sufficiently precise to be able to decide with confidence. Several of them, as those of lead, seem to belong to the first class ; but others, as those of mercury, belong pretty evidently to the second.

To the *third* class belong several of the metallic



oxides, which have been examined with the greatest precision, as those of iron, tin, copper, arsenic. In some of them, the capacity of only combining in the maximum and minimum proportion is exceedingly well marked. Thus the red oxide of iron is converted by heat and by sulphurated hydrogen gas to the black oxide: if the black oxide of copper and metallic copper be mixed together in equal quantities in muriatic acid, the oxygen does not divide itself among the whole of the copper; such a portion of the metal only is oxidated as with the oxygen is capable of forming orange oxide, and the rest of the copper remains unaltered. If copper-filings be confined with muriatic acid in a phial half full and close corked, the acid at first acquires a deep green colour, and of course has combined with a portion of the copper, which must previously have been converted into black oxide; but in a few days it becomes quite colourless. The black oxide is gradually decomposed, more copper is dissolved, and acid is found combined, not with the black but with the orange oxide. Here the process stops, unless we uncork the phial for a few minutes. If that be done, the solution becomes again green, and gradually loses its colour as before. If the phial be opened under water, a quantity of that liquid rushes in; a plain proof that part of the air of the phial has disappeared: and if we examine that air, we find it deprived altogether of its oxygen. The nature of the process then is evident: the copper is supplied with oxygen from the air in the vessel. It at first combines with it in that proportion only which constitutes black oxide; afterwards this black oxide, or rather oxy-muriat, combines with the precise portion of copper necessary to convert it to orange oxide or muriat. If air be again presented, the muriat

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combines with the precise proportion of oxygen which is necessary to convert it into muriat, and so on.

To the *fourth* class belongs *water*, which cannot by any method known be combined in any other proportion than 0.85 oxygen and 0.15 hydrogen. *Ammonia* also belongs to the same class, for it is equally constant in its proportions. It is remarkable that both the component parts of these two bodies are elastic fluids. This elasticity is doubtless the cause of the constancy of the proportions; for it is obvious that there can be only one proportion capable of holding the elasticity of the two component parts in due balance; and if the elasticity of either prevail, the combination cannot take place at all. Substances which are absolutely insoluble, or nearly so, when combined in certain proportions, may also be considered as belonging to the same class, unless the addition of either of the ingredients renders them soluble. Hence the reason of the constancy of the proportions of sulphat of barytes, oxalat of lime, phosphat of lime, fluat of lime, &c.

All compounds belonging to the second and third class have an elastic fluid for one of their ingredients, and those of the third class only manifest their peculiar constitution when they are in combination with some other substance. These observations are sufficient to show that the refusal of bodies to combine, except in their maximum or minimum proportion, or in certain determinate proportions between these two, is owing always, not to the nature of affinity, but to certain peculiarities in their constitution; and that when these peculiarities are not present, these determinate proportions are not observed. But this peculiarity of constitution deserves the highest attention, as we are indebt-

ed to it for that constancy which we find in almost all combinations, and for the permanency of natural bodies in the state in which they have originally combined.

Having thus examined the proportions in which bodies are capable of combining, let us now consider the varieties in the *force* with which they combine, and the attempts which have been made to measure these varieties.

### SECT. III.

#### OF THE STRENGTH OF AFFINITY.

SINCE the affinity of almost every two bodies for each other differs in *strength* from that between every other two, it becomes an important problem to *determine the strength of every affinity in numbers*. The solution of this problem would give a clearness and precision to chemistry equal to that of any other branch of natural philosophy whatever, and enable it to advance with a degree of rapidity hitherto thought unattainable. No wonder, then, that this problem has occupied the attention of some of the most eminent philosophers who have dedicated their time to chemistry. Let us consider the different attempts which have been made to resolve it, that we may see whether any of them will answer the end proposed.

Importance  
of the sub-  
ject.

Wenzel supposed that the time taken by one body to dissolve another is a measure of the affinity which

Solution  
proposed  
by Wenzel,

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subsists between them. But the hypothesis of that ingenious philosopher will not bear the test of examination; for the *time* of solution evidently depends upon circumstances unconnected with affinity. The cohesion of the body to be dissolved, and the nature of the compound formed, must occasion very great differences in the time of solution of different bodies, even on the supposition that their affinities were all the same.

By Fourcroy,

Fourcroy proposed to measure the affinity of bodies by the difficulty of separating them after they are combined: but we have no method of measuring this difficulty. Lavoisier and De la Place, indeed, proposed *caloric* for this purpose; but there are many compounds which caloric cannot separate, and it never produces a separation except by means of its affinity for one or other of the ingredients of the compound. Before caloric, therefore, could be employed as a measure, it would be necessary to know exactly the strength of its own affinity for every other substance; which is just a case of the problem to be resolved.

By Macquer,

Macquer supposed that the affinity of bodies for one another was in the compound ratio of the facility of their union, and the difficulty of their separation. But as we are in possession of no method of ascertaining either of these, it is evident that this theory, even allowing it to be just (which it certainly is not), could be of no use for assisting us to calculate the force of affinities.

By Morveau.

Another method has been proposed by the distinguished philosophical chemist Mr de Morveau\*.

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\* Now Mr Guyton. We have used the old name all along in the text to avoid ambiguity.



In 1713, Dr Brook Taylor made some experiments on the adhesion of surfaces ; and concluded from them, that the force of adhesion might be determined by the weight necessary to produce a separation. But in 1772, Messrs La Grange and Cigna, observing that the surfaces of water and oil adhere together, and taking it for granted that these two liquids *repel* each other, concluded, in consequence, that their adhesion was not owing to *attraction* ; and hence inferred, that *adhesion*, in general, is always owing to the pressure of the atmosphere. This conclusion induced Morveau to examine the subject : he found, that adhesion was *not affected* by the pressure of the atmosphere ; for it required the same weight to separate a disk of glass (30 lines in diameter) from the surface of mercury in the open air, and under an exhausted receiver. He observed that the same disk adhered to water with a force of 258 grains, and to the solution of potass, though denser, only with a force of 110. This result not only proved that adhesion was owing to attraction, but made him conceive the possibility of applying this method to the calculation of affinities : For the force of adhesion being necessarily proportional to the points of contact, and this being the case also with affinity, it is evident, that the adhesion and the affinity between the same substances are proportional, and that therefore the knowledge of the one would furnish us with the ratio of the other.

Struck with this idea, he constructed cylinders of different metals, perfectly round, an inch in diameter and the same in thickness, and having a small ring in their upper surface, by which they might be hung exactly in equilibrium. He suspended these cylinders,

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one after another, to the beam of a balance; and after counterpoising them exactly, applied them to a quantity of mercury placed about two lines below them, making them slide along its surface, to prevent any air from lodging between them and the mercury. He then marked exactly the weight necessary to overcome their adhesion, taking care to change the mercury after every experiment. The TABLE of the results is as follows:

Gold adheres to mercury with a force of	446 gr.
Silver .....	429
Tin .....	418
Lead .....	397
Bismuth .....	372
Platinum .....	282*
Zinc .....	204
Copper .....	142
Antimony .....	126
Iron .....	115
Cobalt .....	8

- The differences of these results cannot be owing to the pressure of the air, which was the same in all; nor do they correspond to the densities of the metals; nor can they be owing to accidental differences in the polish of the cylinders, for a plate of rough iron adheres more strongly to mercury than one of the same diameter exquisitely polished; but they follow precisely the order of affinity, and therefore may be considered as the measure of the strength of the affinity between these different metals and mercury. They furnish us also with a convincing proof that *affinity* is *attraction*, and

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\* Morveau, *Ann. de Chim.* xxv. 10.

the same species of attraction with *adhesion*; and that therefore, if the one be reducible to *gravitation*, so must the other.

Mr Achard, convinced of the importance of Mr Morveau's observations, made a great many experiments on *adhesion*, and published the result of them in 1780. He proved that the force of adhesion is not affected by alterations in the height of the barometer, but that its force becomes weaker as the heat of the fluid increased\*; and that the temperature remaining the same, the force of adhesion increases in the same ratio with the surfaces of the adhering bodies. He made about 600 experiments on the adhesion of different solids and fluids; proved that the force of adhesion did not depend on the densities of the adhering bodies, nor on the different cohesive force of the fluids; and, after a laborious calculation, concluded, that it depended on the figure of the particles of the adhering fluid and solid.

This method of measuring the force of affinities seems to be an accurate one, and if it could be applied to every case of affinity, would, in all probability, enable us to solve the problem which we are now considering: But unfortunately its application is very limited, being confined to those cases alone in which one of the bodies can be presented in a fluid and the other in a solid state. Nor can it be applied indiscriminately to all those cases; for whenever the cohesion of any liquid is much inferior to the force of its adhesion to any solid, the separation takes place in the particles of the liquid itself, and consequently we do not obtain the measure of its

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\* Strictly speaking, this is owing not so much to a decrease of the force of adhesion, as that of the cohesion of the fluid itself.

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adhesion to the solid, but of its own cohesion, and that too imperfectly. Thus, for instance, Mr Achard found, that sealing-wax adhered to water with a force of 92 grains, and to alcohol only with a force of  $53\frac{3}{4}$ ths; yet we know that sealing-wax has a greater affinity for alcohol than for water: because alcohol dissolves it, which water is incapable of doing. The difference in the result in this instance was evidently owing to the smaller cohesion of alcohol. Mr Morveau's method must therefore be confined to those cases in which the cohesion of the liquid is stronger than its adhesion to the solid, which may be known by the surface of the solid not being moistened, and to those in which the cohesion is not much inferior to the adhesion; for then it is evident that the force of cohesion will be increased as the force of adhesion. Let us suppose, for instance, that two solids, A and B, are made to adhere to the surface of a liquid, and that A can only form an adhesion with 50 particles of the liquid, whilst B adheres to 100; it is evident that a much smaller force will destroy the cohesion of the 50 particles to which A adheres with the rest of the liquid, than what will be required to destroy the cohesion of the 100 particles united to B with the same liquid\*.

The method of Mr Morveau, then, may be applied with accuracy in both cases; and *when* they occur can only be determined by experiment. It cannot, however, be applied indiscriminately even then; for unless the solid and the fluid be presented in such a state that no gas is extricated when the adhesion takes place, an accurate judgment cannot be formed of the force of ad-

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\* Morveau, *Encyc. Method. Chim. art. Adhesion.*



hesion. When marble (carbonat of lime), for instance, is applied to the surface of sulphuric acid, there is an extrication of gas, which very soon destroys the adhesion, and prevents an accurate result. Were it possible to employ quicklime instead of marble, this would be prevented; or if this cannot be accomplished, why might not lime be employed, united with some acid that would not assume a gaseous form, and at the same time has a weaker affinity than sulphuric acid for lime? Why might not the phosphat of lime, for instance, be used, which may be reduced to a state of hardness sufficiently great for the purpose? The extrication of gas, during the application of metals to the surfaces of acids, might be prevented by oxidating their surfaces. It is true, indeed, this could not be done with all the metals, on account of the nature of the oxide, but it might with several; copper, for instance, and silver. It cannot be doubted, that by these methods, and other contrivances that might be fallen upon, a sufficient number of results might be obtained to render this method of the greatest importance. It is rather surprising, therefore, that it has never been prosecuted.

Mr Kirwan has proposed another method of solving the problem. While he was engaged in his experiments on the strength of acids, he observed that the quantity of real acid necessary to saturate a given quantity of each of the bases was inversely as the affinity between the respective bases and the acid; and that the quantity of each of the bases necessary to saturate a given quantity of acid was directly as the affinity between the base and the acid. Thus 100 grains of each of the acids require more alkali for saturation than lime, and

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more lime than magnesia, as may be seen in the following TABLE :

100 Grains of	Potass.	Soda.	Lime.	Ammon.	Mag.	Alum.
Sulphuric acid	215	165	110	90	80	75
Nitric acid	215	165	96	87	75	65
Muriatic acid	215	158	89	79	71	55

He concluded, therefore, that the affinity between acids and their bases may be estimated by the quantity of bases necessary for saturation. Thus the affinity between potass and sulphuric acid is 215, and that between nitric acid and lime 96\*.

Bergman long ago established as a principle, under the name of a chemical paradox, that *the stronger any salt was, the less of any other it required for saturation*. Thus, according to him,

100 parts of potass require	78.5	Sulphuric acid
	64	Nitric
	51.5	Muriatic
	42	Carbonic
100 parts of soda . . . . .	177	Sulphuric
	135.5	Nitric
	125	Muriatic
	80	Carbonic

This proposition, which has been admirably illustrated by Morveau †, evidently resolves itself into the two following :

1. A base requires *the more* of an acid for saturation *the stronger* its affinity for that acid is.

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\* *Phil. Trans.* 1783.

† *Encyc. Method. Chim.* 1. 597.

2. An acid requires *the more* of any base for saturation *the greater affinity* it has for that base. Chap. III.

This axiom of Bergman coincides exactly with the observations of Mr Kirwan ; but as it is merely empirical, and as it is often contradicted by the latest experiments on the analysis of salts published by Kirwan, it will be necessary to suspend our judgment till these analytical methods are brought to such a degree of perfection as to decide the point.

Berthollet has lately proposed another method of estimating the strength of affinity, founded on the principles which he himself first developed. This method gives results which deviate if possible still more widely from the received order of affinities than the axiom of Bergman and Kirwan ; but as he has given sufficient reasons to convince us that the received order of affinities is often erroneous, it will be worth while to take a view of his method, in order to discover what new light it will give us to develop the still unknown laws of the variations of affinity. By Berthollet.

As the affinities of bodies vary with their mass, it is obvious that, when we consider the affinities of bodies, we must suppose them always acting in certain determinate proportions. Now it has been observed formerly, that there are certain proportions in which bodies neutralize each other ; and there is reason to believe that in these proportions the affinity exerted by each of the component parts is precisely of the same force. Now if we suppose that the affinity of a given mass of a given body is a constant quantity, which is at least highly probable ; if we suppose farther, that the affinity of a body is the sum of the attractions of all its particles, and consequently that when various bodies of

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different masses exert the same affinity, the absolute affinity of each body is inversely as its mass—we have a method of ascertaining the proportional affinities of various bodies for a body *A*: for the affinity of each body must be inversely as the mass of each body capable of neutralizing a given quantity of *A*. Let it be supposed required to find the proportional affinity of the three bodies *b*, *c*, and *d* for *A*. If to neutralize a given weight of *A* = 1, there be required of

$$b \text{ a weight} = 1$$

$$c \dots\dots\dots = 2$$

$$d \dots\dots\dots = 3$$

Then the affinities of *b*, *c*, and *d* for *A* are respectively as the inverse of the numbers 1, 2, and 3.

$$\text{Affinity of } b = 1 \text{ or } 6$$

$$c = \frac{1}{2} \text{ or } 3$$

$$d = \frac{1}{3} \text{ or } 2$$

Such is the method pointed out by Berthollet, or at least the method which follows as a consequence from his observations. Let us compare it with the late experiments of Kirwan, which may be considered as the most accurate determinations of the proportions of acid and alkali which neutralize each other. These TABLES are the following:

They give us the affinities of the different bases for sulphuric, nitric, muriatic, and carbonic acids, in the following order and intensity.



Salts.	COMPONENT PARTS.			State.
	Basis.	Acid.	Water.	
Carbonat of potass . . .	41.	43.	. . .	Crystallized.
Pearl ash . . . . .	60.	30.	. . .	Dry.
Carbonat of soda . . .	21.58	14.42	. . .	Fully crystallized.
ditto . . . . .	59.86	40.05	. . .	Desiccated.
barytes . . . . .	78.	22.	. . .	Natural or ignited.
strontian . . . . .	69.5	30.	. . .	Natural or ignited.
lime . . . . .	55.	45.	. . .	Natural if pure, or artificial ignited.
magnesia . . . . .	25.	50.	. . .	Crystallized.
common do. . . . .	45.	34.	. . .	Dried at 80°.
Sulphat of potass . . .	54.8	45.2	. . .	Dry.
soda . . . . .	18.48	23.52	. . .	Fully crystallized.
ditto . . . . .	44.	56.	. . .	Desiccated at 700°.
ammonia . . . . .	14.24	54.66	. . .	Natural and pure, artificial ignited.
barytes . . . . .	66.66	33.33	. . .	Natural and pure, artificial ignited.
strontian . . . . .	58.	42.	. . .	Dried at 66°.
lime . . . . .	32.	46.	. . .	Dried at 170°.
ditto . . . . .	35.23	50.39	. . .	Ignited.
ditto . . . . .	38.81	55.84	. . .	Incandescent.
ditto . . . . .	41.	59.	. . .	Fully crystallized.
magnesia . . . . .	17.	29.35	. . .	Desiccated.
ditto . . . . .	36.68	63.32	. . .	Crystallized.
Alum . . . . .	12. ignited	17.66	51. of crystal. + 19.24 in the earth	Desiccated at 700°.
Ditto . . . . .	63.75	36.25	. . .	

TABLE of the Composition of Salts, continued.

Salts.	COMPONENT PARTS.			State.
	Basis.	Acid.	Water.	
Nitrat of potass . . . .	51.8	44.	4.2 of Composition	Dried at 70°.
soda . . . . .	40.58	53.21	6.21 of Composition	Dried at 400°.
ditto . . . . .	42.34	57.55	.	Ignited.
ammonia . . . . .	23.	57.	20.	
barytes . . . . .	57.	32.	11.	Crystallized.
strontian . . . . .	36.21	31.07	32.72	Crystallized.
lime . . . . .	32.	57.44	10.56	Well dried, that is, in Air.
magnesia . . . . .	22.	46.	22.	Crystallized
Muriat of potass . . . .	64.	36.	.	Dried at 80°.
soda . . . . .	53.	47. aqueous, 38.88 real	.	Dried at 80°.
ammonia . . . . .		.	.	Crystallized.
ditto . . . . .	25.	42.75	32.25	Sublimed.
barytes . . . . .	64.	20.	16.	Crystallized.
ditto . . . . .	76.2	23.8	.	Desiccated.
strontian . . . . .	40.	18.	42.	Crystallized.
ditto . . . . .	69.	31.	.	Desiccated.
lime . . . . .	50.	42.	8.	Red hot.
magnesia . . . . .	31.07	34.59.	34.34	Sensibly dry.

I. SULPHURIC ACID.

III. MURIATIC ACID.

Intensity. Intensity.

Ammonia . . . . .	383	Ammonia . . . . .	171
Magnesia . . . . .	171	Magnesia . . . . .	111
Lime . . . . .	143	Lime . . . . .	84
Soda . . . . .	127	Soda . . . . .	73
Potass . . . . .	82	Potass . . . . .	56
Strontian . . . . .	72	Strontian . . . . .	46
Barytes . . . . .	50	Barytes . . . . .	31

II. NITRIC ACID.

IV. CARBONIC ACID.

Intensity. Intensity.

Ammonia . . . . .	245	Ammonia . . . . .	
Magnesia . . . . .	209	Magnesia . . . . .	200
Lime . . . . .	179	Lime . . . . .	81
Soda . . . . .	136	Soda . . . . .	66
Potass . . . . .	85	Potass . . . . .	105
Strontian . . . . .	85	Strontian . . . . .	43
Barytes . . . . .	56	Barytes . . . . .	28

The order and intensity of these four acids for the same bases may be seen from the following TABLE :

Acids.	Potass.	Soda.	Ammonia.	Baryt.	Stront.	Lime,	Magn.
Muriatic	177	136	58	314	216	118	80
Sulphuric	121	78	26	200	131	69	57
Nitric	117	73	40	178	116	50	47
Carbonic	95	149		35	231	122	50

In these Tables we see that the affinities follow the same order, except in the case of carbonic acid, from the nature of which it is not so easy to determine in what proportion it combines with the various bases as it is to determine the same thing with regard to the other acids.

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In the first set of tables, we see that the bases follow precisely the inverse order of what is commonly supposed to be their affinities, and which have been given from Bergman in the preceding part of this Work. Ammonia has the strongest affinity for the acids, and barytes the weakest. This is contrary to the order in which these substances decompose, or rather precipitate each other. Consequently if it be the real order of the affinities of the bases for the acids, decomposition must be determined by something else than the force of affinity.

Why the order of affinity and of decomposition may be different.

If we consider the matter with attention, it will not be difficult to see the reason why the order of affinity and of decomposition is different: Ammonia is an elastic fluid, of course it makes its escape as soon as it is disengaged; and its elasticity conspires to render its disengagement more easy. Hence any substance, how weak soever its affinity is, may be capable of disengaging it from its combination, provided it be added in sufficient quantity and the decomposition be assisted by heat. The disengagement of ammonia then by the other bases is no sufficient proof that its affinity is inferior to them.

Magnesia forms with sulphuric acid a very soluble compound; hence the reason that sulphuric acid is separated from it by barytes, strontian, lime, and potass. These bodies form salts scarcely soluble, and therefore the attraction of cohesion enables them to abstract the acid, notwithstanding the inferiority of their affinity. Magnesia, too, has a strong tendency to cohere together in visible masses. This cohesive tendency is sufficient to enable soda to displace it from sulphuric acid.

This tendency to cohesion may be the reason why



lime is precipitated from its solution in acids in several instances by potass and soda. The superiority of potass over soda has been determined merely on account of the greater insolubility of most of the salts of potass. The same thing has occasioned the supposed superiority of barytes over strontian.

But it would be tedious to examine all the different salts particularly. The causes of their decomposition, even on the supposition that their real affinities are as in the above tables, will easily suggest themselves, at least after the perusal of the next Section.

With respect to the affinity of the acids for the respective bases, they follow the order which has long been recognized in the metallic salts; muriatic acid first, then the sulphuric, and the nitric in the third place. The carbonic acid ought not to be taken into consideration, because the composition of the salts, into which it enters, must still be considered as very imperfectly determined. The reason why muriatic acid has been supposed to have a weaker affinity for the alkalies and earths than sulphuric acid is, that its salts are much more soluble than those into which sulphuric acid enters.

Upon the whole, then, we may consider it as exceedingly probable that the real order of affinities does not deviate far from that given in the above Tables. The method pointed out by Berthollet, for determining the strength of affinities, therefore, will probably lead to consequences of the greatest importance. It will oblige chemists to attend more closely to the reciprocal action of bodies on each other, and the result must be the discovery of several general laws, which will greatly

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facilitate the acquisition and the advancement of the science. Even already some of these have been laid open by Berthollet, as we shall see in the next Section.

## SECT. IV.

## OF COMPOUND AFFINITY.

ALTHOUGH every chemical combination is produced by the same general law, yet as their phenomena vary somewhat according to circumstances, affinities have, for the sake of greater perspicuity, been divided into classes. These classes may be reduced to two, namely, *simple affinity* and *compound affinity*.

Simple affinity.

The *first class* comprehends all those cases in which only *two bodies combine* together; as, for instance, sulphuric acid and potass, oxygen and carbon. The affinities which belong to this class are known by the name of *simple* or *single affinities*. Although one of the substances to be combined happens to be already united with another body, the combination is still reckoned a case of single affinity. Thus suppose the sulphuric acid previously combined with magnesia, and forming with it the salt called *sulphat of magnesia*, as soon as potass is presented, the acid leaves the earth (which is precipitated) and unites with the alkali. Even when three bodies combine, it often happens that the union is produced merely by single affinity. Thus, when some potass is dropped into tartarous acid, part of the acid unites with the alkali, and forms tartrite of potass; after this

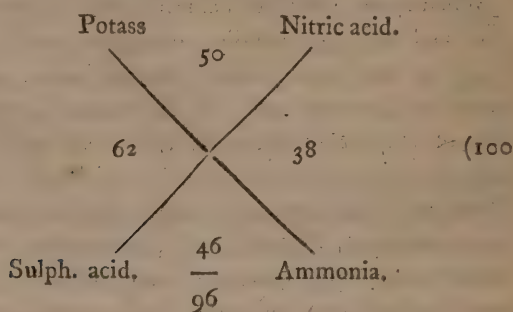
the remainder of the acid combines with the tartrate just formed, and composes a new salt known by the name of *super-tartrate of potass*, or *tartar*. This is evidently nothing else than two instances of simple affinity immediately following each other.

When more than three bodies are mixed, decompositions and new combinations often take place, which would not have been produced had the bodies been presented in a separate state. If, for instance, into a solution of sulphat of ammonia there be poured nitric acid, no decomposition is produced, because the sulphuric acid has a stronger affinity for ammonia than nitric acid has. But if nitrat of potass be poured in, we obtain by evaporation two new bodies, *sulphat of potass* and *nitrat of ammonia*. Such cases of decomposition form the *second class of affinities*. They were called by Bergman cases of *double elective attraction*; a name which is exceedingly proper when there are only four bodies concerned. But as there are often more than four, it is necessary, as Mr Morveau has observed, to employ some more comprehensive term. The phrase *compound affinity* may be employed with propriety, comprehending under the term all cases where more than three bodies are present, and produce combinations which would not have been formed without their united action. In these cases the affinity of all the various bodies for each other acts, and the resulting combination has been supposed to be produced by the action of those affinities which are strongest.

Compound affinity.

The manner in which these combinations and decompositions take place, was thus explained by Dr Black. Let the affinity between potass and sulphuric acid be = 62; that between nitric acid and ammonia = 38;

{ Book III. that between the same acid and potass = 50; and that between the sulphuric acid and ammonia = 46. Now, let us suppose that all these forces are placed so as to draw the ends of two cylinders crossing one another, and fixed in the middle in this manner,



It is evident, that as  $62 + 38 = 100$  are greater than  $50 + 46 = 96$ , they would overcome the other forces and shut the cylinders. Just so the affinity between ammonia and nitric acid, together with that between sulphuric acid and potass, overcomes the affinity between ammonia and sulphuric acid, and that between nitric acid and potass, and produces new combinations.

It has been supposed that in all cases of compound affinity, there are two kinds of affinities to be considered; 1st, Those affinities which tend to preserve the old compound, these Mr Kirwan has called *quiescent* affinities; and those which tend to destroy them, which he has called *divellent* affinities.

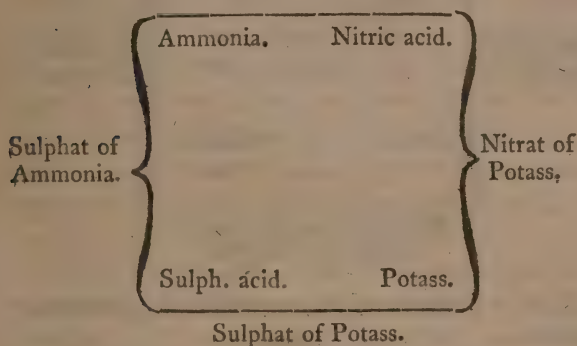
Thus, in the instance above given, the affinity between ammonia and sulphuric acid, and that between nitric acid and potass, are quiescent affinities, which endeavour to preserve the old compound; and if they are strongest, it is evident that no new compound can



take place. On the contrary, the affinity between potass and sulphuric acid, and that between nitric acid and ammonia are divellent affinities; and as they are in this case strongest, they actually destroy the former combinations and form new ones.

Bergman, who published a great many cases of compound affinities, employed to explain them a method somewhat different from this. He would have represented the above case in the following manner:

Nitrat of Ammonia.



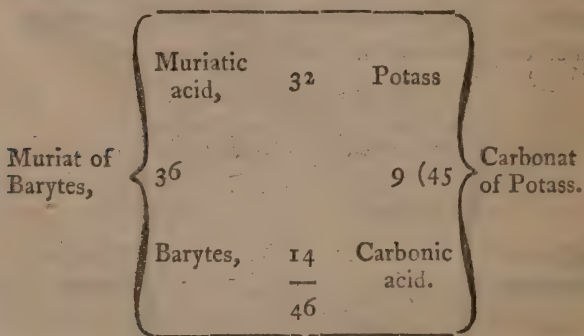
At the four corners of an imaginary square are placed the four substances, so that one acid shall be diagonally opposite to another. On the right and left side of the square are placed the old compounds, each on the side of its own ingredients, and above and below are placed the new compounds.

Mr Elliot improved this method of Bergman, by adding numbers expressive of the affinity of the various substances. These numbers were merely arbitrary, but chosen so as to answer all known cases of decomposition. Thus it was known that muriat of barytes and carbonat of potass mutually decompose each other.

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Therefore supposing that the affinity between the muriatic and barytes = 36; that between the same acid and potass = 32; the affinity between potass and carbonic acid = 9; and that between the same acid and barytes = 14;—we have the following formula of their decomposition:

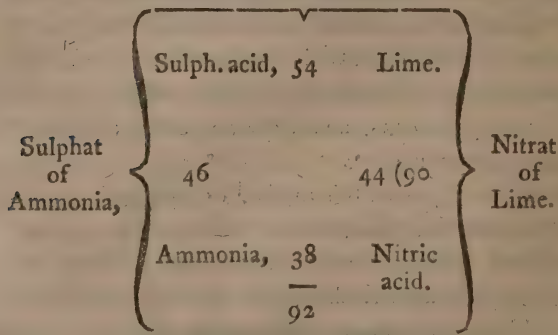
Muriat of Potass.



Carbonat of Barytes.

Another instance of decomposition by compound affinities.

Sulphat of Lime.



Nitrat of Ammonia.

Such were the opinions concerning compound affinity which had been received by all philosophers, in consequence, chiefly, of the dissertation published on the subject by Bergman. But the late experiments of Berthollet have demonstrated, that these opinions were in many respects erroneous, and that chemists had too carelessly admitted the existence of these complete decompositions without sufficient examination.

1. It has been supposed that when two of those salts which mutually decompose each other are mixed together, the decomposition instantly takes place in consequence of the force of affinities alone, independent of the proportions of the ingredients. Thus when *sulphat of potass* and *nitrat of lime* are mixed together, it was supposed that the sulphuric acid, if present in sufficient quantity, combines with the whole of the lime and disengages the nitric acid and the potass, which also combine till the least abundant of the two be saturated. But if this were the case, some of the four ingredients must be left disengaged, as the proportions of the ingredients of the salts formed by the four ingredients are not such as to saturate each other. According to Mr Kirwan's experiments, the proportions of acid and alkali in the four following salts are as under:

Action of salts depends on their proportions.

Sulphat of potass	{	Acid	100
		Potass	121.48
Sulphat of lime	{	Acid	100
		Lime	70
Nitrat of potass	{	Acid	100
		Potass	117.7
Nitrat of lime	{	Acid	100
		Lime	55.7

Now let sulphat of potass and nitrat of lime be mixed

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together; let the quantity of sulphat of potass be such, that the acid contained in it amounts to 100; and let a more than sufficient quantity of nitrat of lime be added, to saturate the sulphuric acid with lime. It is evident that for that purpose 70 of lime must be present; and the quantity of nitric acid combined with these 70 must be 123.8. This quantity would require for saturation 145.7 of potass, but there are only 121.48 in the mixture; consequently there ought to exist in the mixture, after the mutual decomposition of the salts, a quantity of nitric acid in a state of liberty. But the fact is, that no such excess of acid exists in the mixture\*. This is a sufficient proof that the decomposition does not take place in the manner that has been supposed. It may be said, indeed, that the composition of these salts may not be sufficiently known to warrant reasoning from it, But be the proportion of the ingredients what it may, still if the decomposition were absolute, as has been supposed, when mixed in any proportion whatever, except in one, some of the ingredients ought to remain disengaged; but as this does not happen either in this case or in any other, we have a right to conclude that the decomposition is not what it has been considered.

2. When two saline solutions are mixed together, either no apparent change takes place, or a precipitate is formed. Let us consider each of these cases.

When no precipitate takes place they combine.

When no precipitation takes place, the two salts no doubt combine together, and form a compound consisting of the two acids and their bases; and the degree of saturation must be the same as before mixture, because the proportions and the affinities must continue the

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\* *Ann. de Chim.* xxv. 295.



same. Hence the reason that in these cases there are never any indications of any one of the ingredients being disengaged from the others. Hence also the reason that when two salts are dissolved in water, they increase the solubility of each other. Their mutual affinity serving as an additional counterbalance to the cohesion of each. Thus Vauquelin has shewn that saturated solutions of sulphat of lime, alum, and sulphat of potass, are capable of dissolving a greater proportion of common salt than pure water is \*.

3. When two salts may be mixed together without any precipitation taking place, it is a proof that all the salts capable of being formed by the component parts of each are soluble. Hence the alkaline salts very rarely occasion a precipitate when mixed together, nor the earthy salts when the acid combined in each is such as to form soluble salts with all the earthy bases, as nitric acid, muriatic acid. On the other hand, when a precipitate takes place, some two of the ingredients form an insoluble compound; consequently we can easily determine before-hand whether or not a precipitate will take place. It is from this precipitation chiefly that double decompositions have been determined. It is obvious that they are occasioned not by the superiority of the affinity of the ingredients which precipitate, but by the strong tendency which these ingredients have to cohere together. The consequence of which tendency is the exclusion of the other component parts, and the precipitation of the masses as they form. It may be considered, then, as a general law, that "whenever a salt is insoluble, the two ingredients which compose it, when-

The precipitate consists of the least soluble salts.

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\* *Ann. de Chim.* xiii. 89.

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ever they meet in a solution, precipitate in combination." For this general law we are indebted to Mr Berthollet.

Thus barytes forms an insoluble compound with sulphuric acid, phosphoric acid, oxalic acid, tartarous acid, &c. Consequently when a salt, whose base is that earth, is mixed with a salt containing any of these acids, a precipitation takes place consisting of the barytes combined with the acid. *Salts of lime* form a precipitate with oxalats, tartrites, citrats, phosphats, fluats, and sometimes with sulphats. The alkaline carbonats occasion a precipitate in all the earthy salts, because all the earthy carbonats are insoluble. Acetite of lead occasions a precipitate in sulphats, muriats, phosphats, mucites, &c. Nitrat of silver in the muriats. But it would be endless to run over all the precipitates occasioned by the mixture of salts: every person may ascertain them merely by observing what salts are insoluble.

It ought to be observed, however, that the precipitation takes place, not because the salts are insoluble in water, but because they are insoluble in the particular solution in which the precipitate appears. Now if this solution happens to be capable of dissolving any particular salt, that salt will not precipitate, even though it be insoluble in water. Hence the reason why precipitates so often disappear when there is present in the solution an excess of acid, of alkali, &c.

This law has been still further generalized by Berthollet. When different salts are mixed together, they separate either spontaneously, or on evaporation, according to the order of their solubility. Those which are insoluble precipitate immediately on the mixture,

and those which are least soluble crystallize first when the solution is evaporated. Potass forms with sulphuric acid a salt much less soluble than sulphat of soda. Hence the reason why it has been supposed to have a stronger affinity for sulphuric acid, and by analogy for acids in general, than soda: For if sulphat of soda be mixed with the greater number of the salts of potass, sulphat of potass is obtained by evaporation.

But in cases where two salts are mixed together, the resulting salts are much influenced by the proportions of the ingredients. The same salts are not obtained if the ingredients be mixed in one proportion that would be obtained if they were mixed in another proportion. This will appear evidently from the following experiments of Berthollet.

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Salts Mixed.	Proportions.	Precipitate.	First Evaporation.	Second Evaporation.	Mother Water.
Nitrat of lime Sulphat of potass	1 1	Sulphat of lime	Nitrat of potass Sulphat of lime	A little sulphat of potass	Little
Ditto . . . . .	1 2	Ditto	Sulphat of potass Sulphat of lime	Nitrat of potass Sulphat of potass Sulphat of lime	Very little
Ditto . . . . .	2 1	Ditto	Sulphat of lime Nitrat of potass	Nitrat of potass A very little sul- phat of lime.	Abundant*
Sulphat of soda Nitrat of lime	1 1	Sulphat of lime	Nitrat of soda	Nitrat of soda	Abundant†
Ditto . . . . .	2 1	Ditto	Ditto	Ditto	Abundant†

\* Composed of nitrat of lime and nitrat of potass.

† Composed probably of sulphat and nitrat of soda.

† Composed of nitrat of soda and of lime.



Salts Mixed.	Proportions.	First Evaporation.	Second Evaporation.	Third Evaporation.	Mother Water.
Sulphat of soda	1	Sulphat of potass	Nitrat of potass	Nitrat of soda	Considerable*
Nitrat of potass	1	A little nitrat of potass	Some sulphat of potass	Some nitrat of potass	
Ditto . . . . .	2	Sulphat of potass	Sulphat of potass	Sulphat of potass	Considerable*
	1		Some nitrat of potass	Nitrat of potass	
Nitrat of potass	1	Nitrat of potass	Muriat of potass	Nitrat of soda	Abundant†
Muriat of lime	1		Some nitrat of do.		
Ditto . . . . .	2	Muriat of potass			Abundant†
	1	Nitrat of potass	Muriat of potass		Abundant ‡
Muriat of potass	1	Some muriat of do.	Some nitrat of do.		
Nitrat of lime	1				
Sulphat of potass	1	Sulphat of potass	Sulphat of potass	Muriat of potass	Considerable ‡
Muriat of magnesia	1		Muriat of do.	Sulph. of magnesia	
Ditto . . . . .	2		Sulph of pot. & mag.		
	1		Muriat of potass	Ditto	Ditto
	2		Sulphat of potass and-magnesia		

\* Contained both salts.

† Composed of nitrat and muriat of lime.

‡ Composed of all the saline ingredients.

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The mother water, or the liquid which remains when mixtures of salts are separated by crystallization, always contains several salts, or rather their component parts, which are prevented from crystallization by their mutual action on each other. Hence the quantity of this mother water is always the greater the more soluble the salts are; that is to say, the less disposition they have to crystallize.

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## CHAP IV.

## OF REPULSION.

IN the three preceding Chapters the properties of affinity, or of the attraction which influences the particles of bodies, have been examined. But besides attraction, matter possesses another force equally powerful, and equally obvious, and which acts as important a part in the phenomena of nature. This force is *repulsion*, which is no less interesting to the chemical philosopher than attraction, as it is often the antagonist of affinity, and is the chief agent in combustion, fulmination, detonation, evaporation, and indeed in the greater number of the most astonishing and tremendous phenomena of chemistry. It would be improper therefore to leave the general doctrines of chemistry without examining the present state of our knowledge of the laws of repulsion.

1. That there is a force which opposes the approach of bodies towards each other, and which tends to separate them farther from each other, is obvious from the slightest view of the phenomena of nature. When we present the north pole of a magnet A to the same pole of another magnet B, suspended on a pivot, and at liberty to move, the magnet B recedes as the other approaches; and by following it with A at a proper distance, it may be made to turn round on its pivot with considerable velocity. In this case there is evidently some force which opposes the approach of the north poles of A and B, and which causes the moveable magnet to retire before the other. There is then a *repulsion* between the two magnets, a repulsion which increases with the power of the magnets; and this power has been made so great, by a proper combination of magnets, that all the force of a strong man is insufficient to make the two north poles touch each other. The same repulsion is equally obvious on electrical bodies; and indeed it is by means of it alone that the quantity of electricity is measured by philosophers. If two cork balls be suspended from a body with silk threads, so as to touch each other; if we charge the body with electricity, the cork balls separate from each other, and stand at a distance proportional to the quantity of electricity with which the body is charged: the balls of course repel each other.

But it is not in electric and magnetic bodies only that repulsion is perceived. Newton has shewn, that it exists also between two pieces of glass. He found that when a convex lens was put upon a flat glass, it remains at the distance of the  $\frac{1}{137}$ th part of an inch, and a very considerable pressure is required to diminish this

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Proofs of a  
repulsive  
force.

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distance; nor does any force which can be applied bring them into actual mathematical contact: a force may indeed be applied sufficient to break the glasses in pieces, but it may be demonstrated that it does not diminish their distance much beyond the  $\frac{1}{1000}$ th part of an inch. There is therefore a force of repulsion which prevents the two glasses from touching each other. Boscovich has demonstrated, that the same repulsion exists between all hard elastic bodies. When an ivory ball sets another in motion by impinging against it, an equal quantity of its own motion is lost, as is well known. Now Boscovich has shewn, that the ball at rest begins to move while the other is still at a distance.

Thus we see that there exists a repulsion between a great variety of bodies; that this repulsion acts while they are at a distance from each other; that it opposes their approach towards each other; and that it increases as the distance between them diminishes. But this force not only displays itself in bodies of considerable magnitude, it is exerted also by the particles of bodies. That the particles of *air* repel each other is evident; for a considerable force is required to keep them as near each other as we find them at the surface of the earth; and when this force is removed, they separate from each other, that is to say, the air expands. Nor is it known how far this expansion extends. Air has been artificially expanded to 3000 times its usual bulk, and doubtless at great heights in the atmosphere its expansion is still much greater than that. On the other hand, air may be forcibly condensed, that is to say, its particles may be made to approach nearer each other; but a considerable force is required to produce this effect, and this



force increases nearly as the density: if it be removed, the particles again separate, and the air assumes its former bulk. What are the limits of this condensation is not known; but air has been forcibly compressed to the 1000th part of its natural bulk. Thus we see that the particles of air may be made to approach sixteen times nearer each other. The elasticity of air, or the effort which it makes when compressed to resume its former bulk, is evidently the consequence of a repulsive force which its particles exert. All gaseous fluids possess the same repulsive force, and are indebted to it for their elasticity.

The particles of solid elastic bodies likewise repel each other; for they also, when forcibly compressed, resume their former size, and of course their particles repel each other. It has been demonstrated by philosophers, that all liquids are capable of a certain degree of compression, and that when the compressing force is removed they resume their former bulk; consequently the particles of these bodies also repel each other. Farther, it has been shown formerly, that the particles of no body whatever are in mathematical contact; in every case there is a distance between them. Since this is the case, it is obvious that it is possible for these particles to approach nearer each other. But if we make the attempt, we find that all bodies resist compression; many resist it so strongly, that we can produce no sensible change in their size. Consequently there must be some force which opposes the particles of all bodies approaching nearer each other than a certain distance; that is to say, that the particles of all bodies at certain distances repel each other.

2. All bodies then possess a *repulsive force* at cer-

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tain distances, which opposes the diminution of these distances. The cause, or the nature of this force, is equally inscrutable with that of *attraction*, but its existence is undoubted. Like attraction, it exerts itself, either at *sensible* distances or at *insensible* distances; of course the repulsions may be divided into two classes.

## Sensible repulsion.

3. *Sensible* repulsion may very possibly be exerted by two bodies placed at immense distances from each other, as Boscovich has supposed, even beyond the sphere of the attraction of gravitation; but we have no proof of the existence of any such repulsion, unless the permanency of the universe, unaltered by that gravitation which ought to make the different systems gradually approach each other be considered as a proof. The only sensible repulsions with which we are acquainted take place at much smaller distances. They may be reduced to two kinds, namely, *electricity* and *magnetism*. It has been ascertained that bodies possessed of the same kind of electricity repel each other, and likewise the same magnetic poles of bodies repel each other; while, on the other hand, differently electrified bodies and the different poles of magnetic bodies attract each other. Repulsion increases, as far as has been ascertained, inversely as the square of the distance; consequently at the point of contact it is infinite.

## Insensible repulsion,

4. Insensible repulsion is most conspicuous in elastic fluids, as air and the gases; but it is exhibited also by elastic bodies in general. In these, if a judgment can be formed from the experiments on air, the repulsion increases nearly at the rate of  $\frac{1}{d^3}$ .

5. Electric and magnetic repulsion is supposed to reside in a fluid, or rather in two fluids, the particles of

each of which repel those which are similar to themselves, but attract the particles of the other fluid. Insensible repulsion is intimately connected with caloric; a body which has been already examined, and which seems to consist of particles that mutually repel each other. It is well known that the elasticity of air and all other gaseous bodies is increased by heat; or more accurately, that the repulsion between the particles of air, the distance remaining the same, increases with the temperature, so that at last it becomes so great as to overcome every obstacle which can be opposed to it. On the other hand, this repulsion diminishes with the temperature; the consequence of which is, that the external pressure remaining the same, the air is unable to resist it as usual, and of course its particles approach nearer each other.

6. Insensible repulsion may either be a force inherent in the particles of bodies, or it may belong exclusively to some particular body combined with these particles. The first of these hypotheses seems to have been adopted by Newton. In the 31st query at the end of his *Optics*, he gives us his opinion concerning the constitution of nature. He supposes that the primitive particles of matter are similar, extremely hard and dense, and that by their combination they form all the different bodies with which we are acquainted. That these particles have been endowed by their Creator with a certain force, in consequence of which they act mutually on each other, and occasion all the phenomena of the material world; that this force changes with the distance of the particles, not only its intensity, but also its nature; that the particles when at one distance attract, but when this distance is increased or diminished to

Either inherent in all matter,

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a certain extent, the attraction vanishes and repulsion succeeds it.

The ideas of this illustrious philosopher were only delivered in general terms, without applying them to the explanation of particular phenomena. But in 1758, Boscovich published his *Theoria Philosophiæ Naturalis*, in which he gives a detailed explanation of the economy of nature, in principles fundamentally the same with those of Newton, but new modelled with so much ingenuity, and supported by such excellent metaphysical and mathematical reasoning, that he made them entirely his own, and deservedly acquired the reputation of one of the greatest philosophers of the age. According to him, the particles of matter, or the atoms of which all bodies are composed, are mere mathematical points, destitute of extension and magnitude, but capable of acting on each other with a force which differs in intensity and in kind according to the distance. At sensible distances the force is attractive, and diminishes inversely as the square of the distance. At the smallest distances the force is repulsive; it increases as the distance diminishes, and at last becomes infinite or insuperable; so that absolute contact of course is impossible. The space between this last repulsive distance and sensible distances is divided into an indefinite number of parts, alternately attractive and repulsive. Thus let us suppose it divided into ten such parts: while the particles are at any distance between 9 and 10, that is to say, greater than 9 but less than 10, they repel; between 8 and 9 they attract; between 7 and 8 they repel; between 6 and 7 they attract, and so on. At the distances 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, which are the limits between these attracting and repelling spaces, they neither attract



nor repel. The happy explanation which this theory enables Boscovich to give of the greater number of natural phenomena is really astonishing; but there are phenomena which refuse to submit themselves to this ingenious theory; particularly those numerous changes operated on bodies by the action of caloric.

7. Other philosophers have supposed that repulsion is not a property inherent in all matter, but confined to a peculiar substance which has been generally considered as caloric. According to this hypothesis, there are two kinds of matter, one whose particles attract, another whose particles repel. Let us call the first *cohesive matter* and the other *caloric*; and let us suppose also, what must be the case, that cohesive matter and caloric attract each other with a force which varies as some power or function of the distance. In that case we have,

Or confined  
to a peculiar  
substance.

1. The particles of cohesive matter attracting each other,

as  $\frac{1}{d^x} + a$ . 2. The particles of cohesive matter attrac-

ting caloric, as  $\frac{1}{d^y} + b$ . 3. The particles of caloric re-

pellling each other, as  $\frac{1}{d^z} + c$ . To make the case as

simple as possible, let us suppose  $a$ ,  $b$ , and  $c$ , each = 0.

The simplest inspection of the phenomena of nature is sufficient to convince us, that of the three quantities  $y$ ,  $x$ , and  $z$ ,  $x$  must be the least, and that  $y$  and  $z$  cannot differ much from each other. In order to form something like a precise notion of the subject, let us suppose  $x = 2$  and  $y$  and  $z$  each = 3.

Every particle of adhesive matter must be combined with a particle of caloric, and these two must be in actual mathematical contact; for without this supposi-

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tion the phenomena of nature would be inexplicable. Every particle of adhesive matter may also be surrounded with an atmosphere of caloric, which atmospheres will necessarily diminish and alter entirely in the arrangement of the particles which compose them as the two particles of adhesive matter approach each other.

Let us suppose two particles of adhesive matter combined each with a particle of caloric acting upon each other at different distances. The variation of the different attractions and repulsions may be represented by fig. 35. Let the line AB represent the different distances of the two compound particles from each other; one of the particles remaining stationary in A, while the other is moving towards B. The ordinates  $mb, nc, od, pe, qf, rg, sb, ti, uk, xl$ , represent the attractive forces when the second particle is at the points  $m, n, o, p, q, r, s, t, u, x$ , respectively; and the ordinates  $mb', nc', od', \&c.$  represent the repulsive forces at the same points. The curves  $cdefgbikl$ , and  $c'd'e'f'g'b'i'k'l'$ , drawn through the extremities of these ordinates, are the curves of repulsion and attraction. The properties of these curves have been investigated by mathematicians; but it is unnecessary to have recourse to their investigation, as a bare inspection of the figure is sufficient to demonstrate that it is altogether irreconcilable with the phenomena of nature: For since the ordinates of the repulsive curve diminish at a greater rate than those of the attractive, at some particular distance from A they will be equal to each other. Let us suppose them to be equal at  $r$ , and let  $Ar=6$ , and  $rg$  or  $rg'=1$ . Let  $Am=1$ ,  $An=2$ ,  $Ao=3$ ,  $Ap=4$ , &c. Then at the points  $m, n, o, p, \&c.$

we have the repulsive and attractive ordinates equal nearly to the following numbers :

	<i>m</i>	<i>n</i>	<i>o</i>	<i>p</i>	<i>q</i>	<i>r</i>	<i>s</i>	<i>t</i>	<i>u</i>	<i>x</i>
Repuls.	216.00	27.00	7.90	3.20	1.70	1.00	6.2	4.2	2.9	2.1
Attract.	39.60	9.00	4.00	2.20	1.40	1.00	7.3	5.6	4.4	3.6

Now as these forces are opposed to each other, they partly destroy each other ; therefore to find the absolute force by which the two compound particles are repelled or attracted, while the second compound particle is in the points *m*, *n*, *o*, &c. we have only to take the difference between the attracting and repelling ordinates at these points. This gives us the following result :

	<i>m</i>	<i>n</i>	<i>o</i>	<i>p</i>	<i>q</i>	<i>r</i>	<i>s</i>	<i>t</i>	<i>u</i>	<i>x</i>
Rep.	176.40	18.00	3.90	1.00	3.00	0	0.11	0.14	0.15	0.15
Attr.										

The point *r* is evidently a point of cohesion ; as the two particles, when at the distance denoted by it, are neither attracted nor repelled. But the attractions which follow are totally incompatible with the phenomena :

For, instead of diminishing as  $\frac{1}{d^2}$ , they diminish at an incomparably slower rate. The same remark applies to the repulsions.

We are absolutely certain, then, that *x* and *y* are not = 2 and 3. They must be such, that the difference between  $\frac{1}{d^x}$  and  $\frac{1}{d^y}$  is a square ; that is to say, we must

have  $\frac{1}{d^y} - \frac{1}{d^x} = \frac{1}{d^2}$ , for that alone corresponds with the phenomena. The fact is, if the above supposition, that there are two kinds of matter, one repelling and another attracting, be adopted, it is obvious that the rate at which we see the attractions and repulsions of bodies to

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vary, is only the difference between the respective forces which the particles of matter possess. Of course we cannot ascertain these forces except indirectly. Thus if we suppose  $x = 3$ , and  $y = 5$ , and that the two forces are equal as before at the point  $r$ ; that is, let  $rg$  or  $rg' = a$ , then the attractions and repulsions in the different points will be as follows:

	$m$	$n$	$o$	$p$	$q$	$r$	$s$	$t$	$u$	$x$
Rep.	$\frac{6^5}{1^5} a$	$\frac{6^5}{2^5} a$	$\frac{6^5}{3^5} a$	$\frac{6^5}{4^5} a$	$\frac{6^5}{5^5} a$	$a$	$\frac{6^5}{7^5} a$	$\frac{6^5}{8^5} a$	$\frac{6^5}{9^5} a$	$\frac{6^5}{10^5} a$
Attr.	$\frac{6^3}{1^3} a$	$\frac{6^3}{2^3} a$	$\frac{6^3}{3^3} a$	$\frac{6^3}{4^3} a$	$\frac{6^3}{5^3} a$	$a$	$\frac{6^3}{7^3} a$	$\frac{6^3}{8^3} a$	$\frac{6^3}{9^3} a$	$\frac{6^3}{10^3} a$
Rep.	$\frac{6^2}{1^2} a$	$\frac{6^2}{2^2} a$	$\frac{6^2}{3^2} a$	$\frac{6^2}{4^2} a$	$\frac{6^2}{5^2} a$	$0$				
Attr.						$0$	$\frac{6^2}{7^2} a$	$\frac{6^2}{8^2} a$	$\frac{6^2}{9^2} a$	$\frac{6^2}{10^2} a$

Here the rate of variation is always as  $\frac{1}{d^2}$ . The attractive and repulsive curves would assume a very different form from those in the figure. But it is needless to examine the subject farther, as it would be necessary to shew, before admitting the hypothesis, that the repulsion varies at the rate of  $\frac{1}{d^2}$ . If this could be proved, the greater number of the phenomena of nature could be explained, upon this hypothesis, with the same facility as that of Boscovich; and it would have the additional advantage of not assuming the existence of any force whose action is not actually demonstrated by the phenomena. It is obvious that the changes from attractions to repulsion, when more than one such change appears in consequence of varying the distance between bodies, may be accounted for by supposing that part of



the caloric is driven off by the approach of the bodies.

8. Before leaving this subject, it will be worth while to shew, by an example, that the repulsion between the particles of caloric often acts as a real chemical force, and that it affords a key to explain several phenomena which at first sight appear nearly contradictory. Why do bodies require different temperatures in order to unite? and Why does the presence of caloric, in many cases, favour, or rather produce, union, while it prevents or destroys it in others?

Some substances, phosphorus for instance, combine with oxygen at the common temperature of the atmosphere; others, as carbon, require a higher temperature; and others, as hydrogen and azotic gas, do not combine except at a very high temperature. To what are these differences owing?

It is evident, that whatever diminishes the cohesion which exists between the particles of any body, must tend to facilitate their chemical union with the particles of other bodies: this is the reason that bodies combine more easily when held in solution by water, or when they have been previously reduced to a fine powder. Now caloric possesses the property of diminishing cohesion. And one reason why some bodies require a high temperature to cause them to combine is, that at a low temperature the attraction of *cohesion* is in them superior to that of affinity; accordingly, it becomes necessary to weaken that attraction by caloric till it becomes inferior to that of affinity. The quantity of caloric necessary for this purpose must vary according to the strength of the cohesion and of the affinity; it must be inversely as the affinity, and directly as the cohesion. Wherefore, if we knew precisely the force of the cohe-

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sion between the particles of any body, and of the affinity between the particles of that body and of any other, we could easily reduce the temperature necessary to calculation.

That caloric or temperature acts in this manner, cannot be doubted, if we consider that other methods of diminishing the attraction of cohesion may be substituted for it with success. A large lump of charcoal, for instance, will not unite with oxygen at so low a temperature as the same charcoal will do when reduced to a very fine powder; and charcoal will combine with oxygen at a still lower temperature, if it be reduced to its integrant particles, by precipitating it from alcohol, as Dr Priestley did by passing the alcohol through red hot copper. And to shew that there is nothing in the nature of oxygen and carbon which renders a high temperature necessary for their union, if they be presented to each other in different circumstances, they combine at the common temperature of the atmosphere; for if nitric acid, at the temperature of  $60^{\circ}$ , be poured upon charcoal powder, well dried in a close crucible, the charcoal takes fire, owing to its combining with the oxygen of the acid\*: And in some other situations, carbon is so completely divided that it is capable of combining with the oxygen of the atmosphere, or, which is the same thing, of catching fire at the common temperature: this seems to be the case with it in those pyrophori that are formed by distilling to dryness several of the neutral salts which contain acetous acid†. These observations are sufficient to shew, that

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\* Proust and Morveau, *Encyc. Method. Chim.* i. 474.

† Morveau, *ibid.*

caloric is in many cases necessary in order to diminish the attraction of *cohesion*.

But there is a difficulty still remaining: How comes it that certain bodies will combine with oxygen without the assistance of any foreign heat, provided the combination be once begun, though a quantity of caloric is necessary to begin the combination? and that other bodies require to be surrounded by a great quantity of caloric during the whole time of their combining with oxygen? Alcohol, for instance, if once kindled, burns till it is quite consumed; and this is the case with oils also, provided they be furnished with a wick.

We would err very much, were we to suppose that a high temperature is not as necessary to these substances during the whole of their combustion as at the commencement of it; for Mr Monge found, on making the trial, that a candle would not burn after the temperature of the air around it was reduced below a certain point.

All substances which continue to burn after being once kindled are *volatile*, and they burn the easier in proportion to that volatility. The application of a certain quantity of caloric to alcohol volatilizes part of it; that is to say, diminishes the attraction of its cohesion so much that it combines with oxygen. The oxygen which enters into this combination gives out as much heat as volatilizes another portion of the alcohol; which combines with oxygen in its turn; more heat is given out; and thus the process goes on. Oils and tallow exhibit the very same phenomena; only as they are less volatile, it is necessary to assist the process by means of the capillary attraction of the wick, which confines the action of the caloric evolved to a small quantity of oil, and thus enables it to produce the proper effect. In

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short, then, every substance which is capable of continuing to burn after being once kindled is volatile, or capable of being converted into vapour by the degree of heat at first applied. The reason that a live coal will not burn when suspended insulated in the air, is not, as Dr Hutton supposed\*, because its *light* is dissipated; but because the coal cannot be converted into vapour by the degree of heat which it contains, and because the cohesion of its particles is too great to allow it to combine with oxygen without some such change. There are some coals, however, which contain such a quantity of bitumen that they will burn even in the situation supposed by Dr Hutton, and continue to burn, provided they be furnished with any thing to act as a wick. It is needless to add, that bitumen, like oil, is easily converted into vapour.

But this explanation, instead of removing our difficulties, has only served to increase them: For if caloric only acts by diminishing the attraction of cohesion, and converting these substances into vapour, why do not all elastic fluids combine at once without any additional caloric? why do not oxygen and hydrogen, when mixed together in the state of gas, unite at once and form water? and why do not oxygen and azot, which are constantly in contact in the atmosphere, unite also and form nitrous gas? Surely it cannot be the attraction of cohesion that prevents this union. And if it be ascribed to their being already combined with caloric, how comes it that an additional dose of one of the ingredients of a compound decomposes it? Surely, as Mr Monge has observed, this is contrary to all the other operations in chemistry.

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\* On *Light and Heat*.



That the particles of fluids are not destitute of an attraction for each other, is evident from numberless facts. The particles of water draw one another after them in cases of capillary attraction; which is probably owing to the attraction of cohesion. It is owing to the attraction of cohesion, too, that small quantities of water form themselves into spheres; nor is this attraction so weak as not to be perceptible. If a small plate of glass be laid upon a globule of mercury, the globule, notwithstanding the pressure, continues to preserve its round figure. If the plate be gradually charged with weights one after another, the mercury becomes thinner and thinner, and extends itself in the form of a plate; but as soon as the weights are removed, it recovers its globular figure again, and pushes up the glass before it. Here we see the attraction of cohesion, not only superior to gravitation, but actually overcoming an external force \*. And if the workman, after charging his plate of glass with weights, when he is forming mirrors, happen to remove these weights, the mercury which had been forced from under the glass, and was going to separate, is drawn back to its place, and the glass again pushed up. Nor is the attraction of cohesion confined to solids and liquids; it cannot be doubted, that it exists also in gases; at least it is evident, that there subsists an attraction between gases of a different kind: for although oxygen and azotic gas are of different gravities, and ought therefore to occupy different parts of the atmosphere, we find them always mixed together; and this can only be ascribed to an attraction.

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\* Morveau, *Encycl. Meth. Affinité*, p. 543.

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It seems evident, in the first place, that the affinity between the bases of the gases under consideration and oxygen is greater than their affinity for that dose of caloric which produces their elastic form; for when they are combined with oxygen, the same dose will not separate them again. Let us take hydrogen for an instance: The affinity of hydrogen is greater for oxygen than for the caloric which gives it its gaseous form; but the oxygen is also combined with caloric, and there exists an attraction of cohesion between the particles of the hydrogen gas and oxygen gas; the same attraction subsists between those of oxygen gas and hydrogen gas. Now the sum of all these affinities, namely, the affinity between hydrogen and caloric, the affinity between oxygen and caloric, the cohesion of the particles of the hydrogen, and the cohesion of the particles of oxygen—is greater than the affinity between the hydrogen and oxygen; and therefore no decomposition can take place. Let the affinity between

Oxygen and caloric be . . . . .	50
Hydrogen and caloric . . . . .	50
Cohesion of oxygen for hydrogen . . . . .	4
Cohesion of hydrogen . . . . .	2
Sum of quiescent affinities . . . . .	106
The affinity of oxygen and hydrogen . . . . .	105

The quiescent affinities being greater than the divellent affinities, no decomposition can take place.

Let now a quantity of caloric be added to the oxygen and hydrogen gas, it has the property of expanding them, and of course of diminishing their cohesion; while its affinity for them is so small that it may be neglected. Let us suppose that it diminishes the cohesion

of the oxygen 1, and of the hydrogen also 1, their cohesion will now be 3 and 1; and the quiescent affinities being only 104, while the divellent are 105, decomposition would of course take place, and a quantity of caloric would thus be set at liberty to produce the same effects upon the neighbouring particles.

Thus, then, caloric acts only by diminishing cohesion: And the reason that it is required so much in gaseous substances, and in those combinations into which oxygen enters, is the strong affinity of oxygen and the other bases of the gases for caloric; for, owing to the repulsion which exists between the particles of that subtle substance, an effect is produced by adding large doses of it, contrary to what happens in other cases. The more of it is accumulated, the stronger is the repulsion between its particles; and therefore the more powerful is its tendency to fly off: and as this tendency is opposed by its affinity for the body and the cohesion of its particles, it must diminish both these attractions.





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## PART II.

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# CHEMICAL EXAMINATION

OF

# NATURE.

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HAVING, in the First Part of this Work, given a very full detail of the Principles of Chemistry, and a description of the different Substances with which it is necessary for the Chemist to be acquainted, I propose, in this Second Part, to take a view of the different substances as they exist in nature, constituting the material world, that we may ascertain how far the science of chemistry will contribute towards explaining their nature, and accounting for the different changes which they produce on each other. Now the different substances of which the material world, as far as we have access to it, is composed, may be very conveniently arranged under the five following heads:

- |                    |                |
|--------------------|----------------|
| 1. The Atmosphere, | 4. Vegetables, |
| 2. Waters,         | 5. Animals.    |
| 3. Minerals,       |                |

These five divisions will form the subject of the five following Books.

## BOOK I.

OF

## THE ATMOSPHERE.



Book I.



THE atmosphere is that invisible elastic fluid which surrounds the earth to an unknown height, and incloses it on all sides. It received its name from the Greeks, in consequence of the vapours which are continually mixing with it. When the chemist turns his attention to the atmosphere, there are two things which naturally engage his attention: First, to ascertain the substances of which it is composed; and, secondly, to trace the changes to which it is liable. I shall therefore divide this Book into two Chapters. In the first, I shall examine the component parts of the atmosphere; and, in the second, examine the changes to which it is liable under the title of MÉTÉOROLOGY,

## CHAP. I.

## COMPOSITION OF THE ATMOSPHERE.

NEITHER the properties nor the composition of the atmosphere seem to have occupied much of the attention of the ancients. Aristotle considered it as one of the four elements, situated between the regions of *water* and *fire*, and mingled with two *exhalations*, the *dry* and the *moist*; the first of which occasioned thunder, lightning, and wind; while the second produced rain, snow, and hail. The ancients, in general, seem to have considered the blue colour of the sky as essential to the atmosphere; and several of their philosophers believed that it was the constituent principle of other bodies, or at least that air and other bodies are mutually convertible into each other \*. But these opinions continued in the state of vague conjectures till the matter was explained by the sagacity of Hales and of those philosophers who followed his illustrious career.

Opinions of  
the ancients

\* Thus Lucretius:

Semper enim quodcunque fluit de rebus, id omne  
Aeris in magnum fertur mare: qui nisi contra  
Corpora retribuat rebus, recreetque fluentis,  
Omnia jam resoluta forent, et in aera versa.  
Haud igitur cessat gigni de rebus et in res  
Recidere assidue, quoniam fluere omnia constat. *Lib. v. 274.*

Book I.  
Discoveries  
of the mo-  
derns.

It was not till the time of Bacon, who first taught mankind to investigate natural phenomena, that the atmosphere began to be investigated with precision. Galileo introduced the study by pointing out its weight; a subject which was soon after investigated completely by Torricelli, Paschal, &c. Its density and elasticity were ascertained by Boyle and the Florence Academicians. Mariotte measured its dilatibility; Hooke. Newton, Boyle, Derham, pointed out its relation to light, to sound, and to electricity. Newton explained the effect produced upon it by moisture; from which Halley attempted to explain the changes in its weight indicated by the barometer. But a complete enumeration of the discoveries made upon the atmosphere in general belongs to *pneumatics*; a science which treats professedly of the mechanical properties of air.

Component  
parts of the  
atmosphere.

The knowledge of the component parts of the atmosphere did not keep pace with the investigation of its mechanical properties. The opinions of the earlier chemists concerning it are too vague and absurd to merit any particular notice. Boyle, however, and his contemporaries, put it beyond doubt that the atmosphere contained two distinct substances. 1. An elastic fluid distinguished by the name of *air*. 2. Water in the state of vapour. Besides these two bodies, it was supposed that the atmosphere contained a great variety of other substances, which were continually mixing with it from the earth, and which often altered its properties, and rendered it noxious or fatal. Since the discovery of carbonic acid gas by Dr Black, it has been ascertained that this elastic fluid always constitutes a part of the atmosphere. The constituent parts of the atmosphere therefore are,



1. Air,                      3. Carbonic acid gas,  
2. Water,                      4. Unknown bodies.

These shall form the subject of the four following Sections. But before proceeding to ascertain their properties, and the proportion in which they exist in air, it will be worth while to endeavour to calculate the amount of the whole of the atmosphere which surrounds the earth. This will put it in our power to state the amount of its different constituent parts, and of course to see how far the quantities of each agree with the different chemical theories which have been maintained concerning the influence of these bodies on the different kingdoms of nature.

Mechanical philosophers have demonstrated, that the weight of a column of the atmosphere, whose base is an inch square, is equal to a column of mercury of the same base, and balanced by the atmosphere in the barometrical tube. Now let us suppose the mean height of the barometer to amount to nearly 30 inches. Let  $R$  denote the radius of the earth,  $r$  the height of the mercury in the barometer,  $\pi$  the ratio between the circumference of a circle and its diameter. The solidity of the earth is  $\frac{4\pi R^3}{3}$ ; the solidity of the sphere composed of the earth, and a quantity of mercury surrounding it equal to the weight of the atmosphere, is  $\frac{4\pi (R+r)^3}{3}$ . Consequently the solidity of the hollow sphere of mercury equal to the weight of the atmosphere, is  $\frac{4\pi (R+r)^3}{3} - \frac{4\pi R^3}{3} = 4\pi (R^2 r + r^2 R + \frac{r^3}{3})$ , or, neglecting the terms containing  $r^2$  and  $r^3$ ,

Its absolute quantity,

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$4 \pi R^2 r$ . This formula, by substituting for  $\pi$ ,  $R^2$  and  $r$ , their known values, gives us the solidity of the hollow sphere of mercury in cubic feet. But a cubic foot of mercury is nearly equal to 135,000 avoirdupois ounces. Hence the mean weight of the atmosphere amounts to about 11911163227258181818 lbs. avoirdupois.

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## SECT. I.

### OF AIR.

Air an elastic fluid.

THE word AIR seems to have been used at first to have denoted the atmosphere in general; but philosophers afterwards restricted it to the elastic fluid, which constitutes the greatest and the most important part of the atmosphere, excluding the water and the other foreign bodies which are occasionally found mixed with it. For many years all permanently elastic fluids were considered as air, from whatever combinations they were extricated, and supposed to possess exactly the same properties with the air of the atmosphere. It is true, indeed, that Van Helmont suspected that elastic fluids possessed different properties; and that Boyle ascertained that all elastic fluids were not capable of supporting combustion like air. But it was not till the discoveries of Cavendish and Priestley had demonstrated the peculiar properties of a variety of elastic fluids, that philosophers became sensible that there existed a variety of species of them. In consequence of this discovery, the

word *air* became generic, and was applied by Priestley, and the British and Swedish philosophers in general, to all permanently elastic fluids, while the air of the atmosphere was distinguished by the epithets of *common* or *atmospheric* air: but Macquer thought proper to apply the term *gas*, first employed by Van Helmont, to all permanently elastic fluids except common air, and to confine the term *air* to this last fluid. This innovation was scarcely necessary; but as it has now been generally adopted, it will be proper to follow it. By the word *air*, then, in this Section, I mean only common *air*, or the fluid which forms by far the greatest part of the atmosphere.

The foreign bodies which are mixed or united with air in the atmosphere are so minute in quantity compared to it, that they have no very sensible influence on its properties. We may therefore consider atmospheric air, when in its usual state of dryness, as sufficiently pure for examination.

1. Air is an elastic fluid, invisible indeed, but easily recognised by its properties. Its specific gravity, according to the experiments of Sir George Shuckburgh, when the barometer is at 30 inches, and the thermometer between  $50^{\circ}$  and  $60^{\circ}$ , is 0.0012, or 816 times lighter than water. One hundred cubic inches of air weigh 31 grains troy.

Specific  
gravity.

But as air is an elastic fluid, and compressed at the surface of the earth by the whole weight of the incumbent atmosphere, its density diminishes according to its height above the surface of the earth. From the experiments of Paschal, Deluc, General Roy, &c. it has been ascertained, that the density diminishes in the ratio of the compression. Consequently the density de-

Density.

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creases in a geometrical progression, while the heights increase in an arithmetical progression.

Bouguer had suspected, from his observations made on the Andes, that at considerable heights the density of the air is no longer proportional to the compressing force\*; but the experiments of Saussure junior, made upon Mount Rosé, have demonstrated the contrary†.

Dilatability.

2. Air is dilated by heat. From the experiments of General Roy and Sir George Shuckburgh, compared with those of Trembley, &c. it appears, that at the temperature of  $60^{\circ}$ , every degree of temperature increases the bulk of air about  $\frac{1}{82}$  part. But the experiments of Du Vernois and Morveau, which gives us the dilatation of air for every degree of Réaumur from  $0^{\circ}$  to  $80^{\circ}$ , have been given in a former part of this Work, and they are the most complete which have hitherto appeared.

3. The specific caloric of air, according to the experiments of Dr Crawford, is 1.79.

Colour.

4. Although the sky is well known to have a blue colour, yet it cannot be doubted that air itself is altogether colourless and invisible. The blue colour of the sky is occasioned by the vapours which are always mixed with the air, and which have the property of reflecting the blue rays more copiously than any other. This has been proved by the experiments which Saussure made with his *cyanometer* at different heights above the surface of the earth. This consisted of a circular band of paper, divided into 51 parts, each of which were painted with a different shade of blue; beginning with

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\* *Mem. Par.* 1753, p. 515.

† *Jour. de Phys.* xxxvi. 98.



the deepest mixed with black, to the lightest mixed with white. He found that the colour of the sky always corresponds with a deeper shade of blue the higher the observer is placed above the surface; consequently, at a certain height, the blue will disappear altogether, and the sky appear black; that is to say, will reflect no light at all. The colour becomes always lighter in proportion to the vapours mixed with the air. Hence it is evidently owing to them\*.

5. The property which the air has of supporting combustion, and the necessity of it for respiration, are too well known to require any description.

6. For many ages air was considered as an element or simple substance. For the knowledge of its component parts, we are indebted to the labours of those philosophers in whose hands chemistry advanced with such rapidity during the last forty years of the 18th century. The first step was made by Dr Priestley in 1774, by the discovery of oxygen gas. This gas, according to the prevailing theory of the time, he considered as air totally deprived of phlogiston; azotic gas, on the other hand, was air saturated with phlogiston. Hence he considered common air as oxygen gas combined with an indefinite portion of phlogiston, varying in purity according to that portion; being always the purer the smaller a quantity of phlogiston it contained.

Composition.

While Dr Priestley was making experiments on oxygen gas, Scheele proceeded to the analysis of air in a different manner. He observed that the liquid sulphurets, phosphorus, and various other bodies, when confined along with air, have the property of diminishing

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\* Saussure's *Voyages dans les Alpes*, iv. 288.

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its bulk; and this diminution always amounts to a certain proportion, which he found to be between a third and a fourth part of the whole. The residuum was unfit for supporting flame, and was not diminished by any of the processes which diminish common air. To this residuum he gave the name of *foul air*. From these experiments, he concluded that air is a compound of two different elastic fluids; namely, *foul air*, which constitutes more than two thirds of the whole, and *another air*, which is alone capable of supporting flame and animal life. This last air he extricated from nitre by heat, from the black oxide of manganese, and from other substances, and gave it the name of *empyrean air*. He showed that a mixture of two parts of foul air and one part of empyrean air possesses the properties of common air\*.

The foul air of Scheele was the same with the phlogisticated air of Priestley, or with what is now known by the name of *azotic gas*. His empyrean air is the same with the dephlogisticated air of Priestley, or with what is at present called *oxygen gas*. According to him, therefore, air is a compound of two parts of azotic and one part of oxygen gas. He accounted for the diminution of air by the liquid sulphurets and other similar bodies by his theory of the composition of caloric, which he considered as a compound of phlogiston and oxygen gas. According to him, the phlogiston of the sulphuret combines with the oxygen of the air, and passes through the vessels in the state of caloric, while the azotic gas, which has no affinity for caloric, is left behind.

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\* Scheele on *Air and Fire*, p. 7. &c. Engl. Trans.

While Scheele was occupied with his experiments on air, Lavoisier was assiduously employed on the same subject, and was led by a different road to precisely the same conclusion as Scheele. By oxidating mercury in a vessel filled with common air, and heated to the boiling point of mercury, he abstracted the greater part of its oxygen gas; and by heating the red oxide thus formed, he reconverted it into mercury, while at the same time a quantity of oxygen gas was extricated. The residuum in the first experiment possessed the properties of azotic gas; but when the oxygen gas extricated from the mercury was added to it, the mixture assumed again the properties of common air. Hence he concluded that air is composed of azotic gas and oxygen; and from a variety of experiments he determined the proportions to be 73 parts of azotic gas and 27 parts of oxygen gas. He demonstrated, too, that when air is diminished by liquid sulphurets, metals, &c. the oxygen gas which is abstracted combines with the sulphurets, &c. and converts them into acids or oxides according to their respective nature. But as all these experiments have been already detailed in the First Part of this Work, it is unnecessary to be more particular in this place.

Air, then, is a compound of oxygen and azotic gas: but it becomes a question of considerable consequence to determine the proportion of these two ingredients, and to ascertain whether that proportion is in every case the same. Since azotic gas, one of the component parts of that fluid, cannot be separated by any substance with which chemists are acquainted, the analysis of air can only be attempted by exposing it to the action of those bodies which have the property of absorbing its oxygen. By these bodies the oxygen gas is separated, and

Air composed of oxygen and azotic gas.

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Method of  
ascertain-  
ing the pro-  
portion of  
its compo-  
nent parts.

the azotic gas is left behind, and the proportion of oxygen may be ascertained by the diminution of bulk; which, once known, it is easy to ascertain the proportion of azotic gas, and thus to determine the exact relative quantity of the component parts.

After the composition of the atmosphere was known to philosophers, it was taken for granted that the proportion of its oxygen varies in different times and in different places; and that upon this variation the purity or noxious qualities of air depended. Hence it became an object of the greatest importance to be in possession of a method of determining readily the quantity of oxygen in a given portion of air. Accordingly various methods were proposed, all of them depending upon the property which a variety of bodies possess of absorbing the oxygen of the air, without acting upon its azot. These bodies were mixed with a certain known quantity of atmospheric air, in graduated glass vessels inverted over water, and the proportion of oxygen was determined by the diminution of bulk. These instruments received the name of *eudiometers*, because they were considered as measurers of the purity of air. The *eudiometers* proposed by different chemists may be reduced to five.

Eudiometer  
of Priestley  
and Fonta-  
na.

1. The first eudiometer was made in consequence of Dr Priestley's discovery, that when nitrous gas is mixed with air over water, the bulk of the mixture diminishes rapidly, in consequence of the combination of the gas with the oxygen of the air, and the absorption of the nitric acid thus formed by the water. When nitrous gas is mixed with azotic gas, no diminution at all takes place. When it is mixed with oxygen gas in proper proportions, the absorption is complete. Hence it is



evident, that in all cases of a mixture of these two gases, the diminution will be proportional to the quantity of the oxygen. Of course it will indicate the proportion of oxygen in air; and by mixing it with different portions of air, it will indicate the different quantities of oxygen which they contain, provided the component parts of air be susceptible of variation. Dr Priestley's method was to mix together equal bulks of air and nitrous gas in a low jar, and then to transfer the mixture into a narrow graduated glass tube about three feet long, in order to measure the diminution of bulk. He expressed this diminution by the number of hundred parts remaining. Thus, suppose he had mixed together equal parts of nitrous gas and air, the sum total of this mixture was 200 (or 2.00): suppose the residuum when measured in the graduated tube to amount to 104 (or 1.04), and of course that 96 parts of the whole had disappeared, he denoted the purity of the air thus tried by 104. A more convenient instrument was invented by Dr Falconer of Bath; and Fontana greatly improved this method of measuring the purity of air. A description of his eudiometer was published by Ingenhouthz in the first volume of his Experiments; it was still farther improved by Cavendish in 1783\*; and Humbolt has lately made a very laborious set of experiments in order to bring it to a state of complete accuracy. But after all the exertions of these philosophers, the method of analysing air by means of nitrous gas is liable to so many anomalies, that it cannot be depended on.

Priestley and Fontana have proved, that the way of

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\* *Phil. Trans.* lxxiii. 107.

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mixing the two airs occasions a great difference in the result ; the figure of the vessels is equally important, and so is the water over which the mixture is made. And even when all these things are the same, impurity of the nitrous gas may occasion the most enormous differences in the results.

Humbolt has shown, that the nitrous gas ought to be prepared by means of nitric acid of the density 1.170 ; when a much stronger or weaker acid is employed, the gas produced is always contaminated with a great proportion of azotic gas. He has pointed out the solution of sulphat of iron, as proper to ascertain the purity of the nitrous gas employed, by absorbing the nitrous gas and leaving the azotic gas or other foreign gases. He has shown, that when nitrous gas of the same degree of purity is made to mix very slowly with air, the vessel being carefully agitated during the mixture, the results, provided the experiment be performed with address, correspond with each other. And he has made it probable, that when equal quantities of air and nitrous gas, so pure as to contain only about 0.1 of azotic gas mixed with it, are agitated together slowly over water, the diminution divided by 3.55 gives the quantity of oxygen contained in the air examined. But notwithstanding the ingenuity of his experiments, the anomalies attending this method are still so great as not to render it susceptible of accuracy. For that reason I think it unnecessary to give a particular description of the different eudiometers invented to ascertain the purity of air by means of nitrous gas. The result of the numerous experiments which have been made with nitrous gas is, that the proportion of oxygen in atmospheric air varies in different places and at different times. The mini-

mum is about 0.22, the maximum about 0.30; consequently if this method of analysing air is to be depended on, we must consider that fluid, not as a permanent chemical compound, but as a body subjected to all the variations to which accidental mixtures are liable.

2. The second kind of eudiometer was proposed by Volta. The substance employed by that philosopher to separate the oxygen from the air was hydrogen gas. His method was to mix given proportions of the air to be examined and hydrogen gas in a graduated glass tube; to fire the mixture by an electric spark; and to judge of the purity of the air by the bulk of the residuum. But this method is not susceptible of so great a degree of accuracy as the preceding, when the object is to ascertain the precise quantity of oxygen gas in a given bulk of air. For if too little hydrogen gas be mixed with the air, not only the whole of the oxygen will not be abstracted, but a portion of the azot will disappear in consequence of the formation of nitric acid. On the other hand, if too much hydrogen be added, part of it will remain after the firing of the mixture, and increase the bulk of the residuum. Volta's eudiometer, then, though it may have its uses, is scarcely susceptible of giving us the analysis of air.

Eudiometer  
of Volta.

3. For the third kind of eudiometer, we are indebted to Scheele. It is merely a graduated glass vessel, containing a given quantity of air exposed to newly prepared liquid alkaline or earthy sulphurets, or to a mixture of iron-filings and sulphur, formed into a paste with water. These substances absorb the whole of the oxygen of the air, which converts a portion of the sulphur into an acid. The oxygen contained in the air

Eudiometer  
of Scheele

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thus examined, is judged of by the diminution of bulk which the air has undergone. This method is not only exceedingly simple, but it requires very little address, and yet is susceptible of as great accuracy as any other whatever. The only objection to which it is liable is its slowness; for when the quantity of air operated on is considerable, several days elapse before the diminution has reached its maximum.

Improved  
by De Mar-  
ti.

But this objection has been completely obviated by Mr De Marti, who has brought Scheele's eudiometer to a state of perfection. He found that a mixture of iron filings and sulphur does not answer well, because it emits a small quantity of hydrogen gas, evolved by the action of the sulphuric acid formed by the absorption of the oxygen of the air upon the iron; but the hydrogenated sulphurets, formed by boiling together sulphur and liquid potass or lime-water, answered the purpose perfectly. These substances, indeed, when newly prepared, have the property of absorbing a small portion of azotic gas; but they lose this property when saturated with that gas, which is easily affected by agitating them for a few minutes with a small portion of atmospheric air. His apparatus is merely a glass tube, ten inches long, and rather less than half an inch in diameter, open at one end, and hermetically sealed at the other. The close end is divided into 100 equal parts, having an interval of one line between each division. The use of this tube is to measure the portion of air to be employed in the experiment. The tube is filled with water; and by allowing the water to run out gradually while the tube is inverted, and the open end kept shut with the finger, the graduated part is exactly filled with air. These hundred parts of air are intro-



duced into a glass bottle filled with liquid sulphuret of lime previously saturated with azotic gas, and capable of holding from two to four times the bulk of the air introduced. The bottle is then to be corked with a ground glass stopper, and agitated for five minutes. After this the cork is to be withdrawn while the mouth of the phial is under water; and for the greater security, it may be corked and agitated again. After this, the air is to be again transferred to the graduated glass tube, in order to ascertain the diminution of its bulk\*.

Air, examined by this process, suffers precisely the same diminution in whatever circumstances the experiments are made: no variation is observed whether the wind be high or low, or from what quarter soever it blows; whether the air tried be moist or dry, hot or cold; whether the barometer be high or low. Neither the season of the year, nor the situation of the place, its vicinity to the sea, to marshes, or to mountains, make any difference. Mr De Marti found the diminution always between 0.21 and 0.23. Hence we may conclude that air is composed of

0.78 azotic gas

0.22 oxygen gas

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1.00

Scheele indeed found, that the absorption amounted to 0.27\*; but that was because he neglected to saturate his sulphuret with azotic gas; for when the portion of azotic gas which must have been absorbed, and which has been indicated by De Marti, is subtracted, the portion of oxygen in air, as indicated by his experiments,

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\* *Jour. de Phys.* lii. 176.

\* Scheele, ii. 1.

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is reduced very nearly to 0.22. The trifling variations perceptible in his experiments were no doubt owing to the quantities of the mixture of sulphur and iron, by which he abstracted the oxygen, not being exactly the same at different times; the consequence of which would be an unequal absorption of azotic gas.

Eudiometer  
of Berthol-  
let.

4. In the fourth kind of eudiometer, the abstraction of the oxygen of air is accomplished by means of phosphorus. This eudiometer was first proposed by Aichard \*. It was considerably improved by Reboul †, and by Seguin and Lavoisier ‡; but Berthollet § has lately brought it to a state of perfection, as it is equally simple with the eudiometer of De Marti, and scarcely inferior to it in precision.

Instead of the rapid combustion of phosphorus, this last philosopher has substituted its spontaneous combustion, which absorbs the oxygen of air completely; and when the quantity of air operated on is small, the process is over in a short time. The whole apparatus consists in a narrow graduated tube of glass containing the air to be examined, into which is introduced a cylinder of phosphorus fixed upon a glass rod, while the tube stands inverted over water. The phosphorus should be so long as to traverse nearly the whole of the air. Immediately white vapours rise from the phosphorus and fill the tube. These continue till the whole of the oxygen combines with phosphorus. They consist of phosphorous acid, which falls by its weight to the bottom of the vessel, and is absorbed by

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\* *Jour. de Phys.* 1784, vol. i.

† *Ann. de Chim.* xiii. 38.

‡ *Ibid.* ix. 293.

§ *Ibid.* xxxiv. 73. and *Jour. de l'Ecole Polytechn.* I. iii. 274.

the water. The residuum is merely the azotic gas of the air, holding a portion of phosphorus in solution. Berthollet has ascertained, that by this foreign body its bulk is increased  $\frac{1}{40}$ th part. Consequently the bulk of the residuum diminished by  $\frac{1}{40}$ , gives us the bulk of the azotic gas of the air examined; which bulk subtracted from the original mass of air, gives us the proportion of oxygen gas contained in it.

All the different experiments which have been made by means of this eudiometer agree precisely in their result, and indicate that the proportions of the ingredients of air are always the same; namely, about 0.22 parts of oxygen gas, and 0.78 of azotic gas. Berthollet found these proportions in Egypt and in France, and I have found them constantly in Edinburgh in all the different seasons of the year. Thus we see that the analysis of air, by means of phosphorus, agrees precisely with its analysis by means of hydrogenated sulphurets.

5 The fifth eudiometer has been lately proposed by Mr Davy. In it the substance used to absorb the oxygen from air is a solution of sulphat or muriat of iron in water, and impregnated with nitrous gas. A small graduated glass tube, filled with the air to be examined, is plunged into the nitrous solution, and moved a little backwards and forwards. The whole of the oxygen is absorbed in a few minutes. The state of greatest absorption ought to be marked, as the mixture afterwards emits a little gas which would alter the result. By means of this and the two preceding eudiometers, Mr Davy examined the air at Bristol, and found it always to contain about 0.21 of oxygen. Air sent to Dr Beddoes from the coast of Guinea gave exactly the same

Eudiometer  
of Davy.

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Method of  
ascertain-  
ing the den-  
sity of the  
air operated  
on.

result. This eudiometer, then, corresponds exactly with the two last \*.

In all these different methods of analysing air, it is necessary to operate on air of a determinate density, and to take care that the residuum be neither more condensed nor dilated than the air was when first operated on. If these things are not attended to, no dependance whatever can be placed upon the result of the experiments, how carefully soever they may have been performed. Now there are three things which alter the volume of air and other elastic fluids: 1. A change in the height of the barometer. 2. An increase or diminution of their quantity; the vessel in which they are contained remaining the same, and standing in the same quantity of water or mercury. 3. A change in the temperature of the air.

How to re-  
duce air to  
a given ba-  
rometrical  
pressure.

1. The density of air and other elastic fluids is always proportional to the compressing force. Now they are compressed by the weight of the atmosphere, which is measured by the barometer. If that weight diminishes, their density diminishes in proportion, and of course their bulk increases: if the weight of the atmosphere increases, their density increases, and their bulk diminishes in the same proportion. Consequently if the height of the barometer varies during an experiment, the bulk of the residuum will not be the same that it would have been if no such change had taken place. We will therefore commit an error unless we reduce the bulk of the residuum to what it would have been if no such alteration had taken place. This is easily done by a very simple formula.

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\* *Phil. Mag.* x. 56.



It has been ascertained by philosophers, that the volumes of air are always inversely as the compressing forces. Therefore let  $m$  be the height of the barometer at the commencement of an experiment,  $n$  its height at the end;  $v$  the volume of the gas when the barometer is at  $n$ , and  $x$  its volume supposing the barometer at

$m$ . We have  $n : m :: x : v$ . Consequently  $x = \frac{n v}{m}$

So that to find the volume required, we have only to multiply the volume obtained by the actual height of the barometer, and divide by the height of the barometer at which we want to know the volume: And, in general, to reduce a volume of air to the volume it would occupy, supposing the barometer at 30 inches, we have only to use the above formula, substituting 30 in place of  $m$ .

2. When air is confined in a jar standing over water or mercury, its density is not the same with that of the atmosphere, unless its lower surface in the jar be exactly level with the surface of the liquid in the tub in which it stands. Let A (fig. 36.) be a jar containing air, and BC the surface of the water or mercury in the tub in which the jar is inverted; the air within the jar is not of the same density with the external air, unless it fills exactly that part of the jar above BC. If it fill only that part of it between A and D while the water or mercury rises to D, the air will be more dilated than the external air, because it is compressed only by the weight of the atmosphere, diminished by the column of mercury or water Dm. On the other hand, if the water or mercury only rise in the jar to E, the air within it will be denser than the external, because it is compressed by the weight of the atmosphere, and also by

To reduce  
it to the  
density of  
external  
air.

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the column of water or air  $m$  E. It is proper therefore, in all cases, to bring the lower surface of the air in the jar to the same level with the surface of the water or mercury in the trough. But in eudiometrical experiments this is often impossible; because part of the air being absorbed, though the water or mercury over which it stands at first only rose to  $m$ , yet the absorption which takes place occasions it to rise to some line D above  $m$ . Hence the air which remains after the experiment is in a state of dilatation, and must be reduced by calculation to the volume which it would occupy were it in the same state of compression as at the commencement of the experiment. This is easily done by the following formula.

Let us suppose the experiment is made over mercury. Let  $H$  be the height of the barometer at the commencement of the experiment,  $b$  the length of the column of mercury  $m$  D,  $v$  the volume of the air in AD, and  $x$  the volume required, or the volume which the air would have supposing D to coincide with  $m$ . Then we have  $H : H - b :: v : x$ . And  $x = \frac{(H - b) v}{H}$ . Thus

let  $H$  be 30 inches,  $b = 5$  inches, and  $v = 200$  cubic inches; then  $x = 166\frac{2}{3}$  cubic inches; so that without this correction the error would amount to no less than  $33\frac{1}{3}$  cubic inches, or about the sixth part of the whole. When the experiment is made over water, the same formula applies; only in that case  $H$  must be multiplied by 13.6, because a column of water 13.6 times longer than mercury is necessary to produce the same pressure. In that case, supposing the numbers the same as before,  $x$  would be  $= 197\frac{1}{2}$ ; so that the error

over water is only  $2\frac{1}{2}$  inches, or the 80th part of the whole.

3. A change in the temperature may be more easily guarded against in eudiometrical experiments, as they are usually made within doors: but when it does happen, it occasions an alteration in the volume of the air; an increase of temperature dilating it, and a diminution of temperature occasioning a condensation. This error may be easily corrected in air and all other gases, by increasing or diminishing their apparent bulk for every degree of change in the thermometer, according to the Table of the dilations of the gases formerly given\*.

Allowance  
for tempe-  
rature.

We may consider it as established by experiment, that air is composed of 0.22 of oxygen gas, and 0.78 of azotic gas by bulk. But as the weight of these two gases is not exactly the same, the proportion of the component parts by weight will differ a little: For as the specific gravity of oxygen gas is to that of azotic gas as 135 : 115, it follows that 100 parts of air are composed by weight of about

Composi-  
tion of air.

74 azotic gas  
26 oxygen gas

100

which differs very little from the determination of Lavoisier, provided that philosopher meant to denote by his numbers the weight and not the volume of the component parts of air.

7. Having thus ascertained the nature and the proportion of the component parts of air, it remains only to enquire in what manner these component parts are united. Are they merely mixed together mechanically,

Air a che-  
mical com-  
pound.

\* Volume I. p. 269.

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or are they combined chemically? Is air a mechanical mixture or a chemical compound? Philosophers seem at first to have adopted the former of these opinions, if we except Scheele, who always considered air as a chemical compound. But the supposition that air is a mechanical mixture, by no means agrees with the phenomena which it exhibits. If the two gases were only mixed together as their specific gravity is different, it is scarcely possible that they would be uniformly mixed in every part of the atmosphere. Even Mr Dalton's ingenious supposition, that they neither attract nor repel each other, would not account for this equal distribution: for undoubtedly, on that supposition, they would arrange themselves according to their specific gravity. Since therefore air is in all places composed of the same ingredients, exactly in the same proportions, it follows that its component parts are not only mixed, but actually combined. When substances differing in specific gravity combine together, the specific gravity of the compound is usually greater than the mean. This holds also with respect to air. The specific gravity, by calculation, amounts only to 0.00119, whereas it actually is 0.0012; a difference by no means inconsiderable. But perhaps the specific gravity of azotic and oxygen gas can scarcely be considered as known with such precision as to entitle us to draw any consequence from this difference.

But the difference between air and a mere mixture of its two component parts has been demonstrated by the experiments of Morozzo and Humbolt. The artificial mixture is much more diminished by nitrous gas than air, even when the mixture contains less oxygen\*. It

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\* Humbolt, *Ann. de Chim.* xxviii. 162.



supports flame better and longer, and animals do not live in it the same time that they do in an equal portion of air, but longer †.

We must therefore consider air as a chemical compound. Hence the reason that it is in all cases the same, notwithstanding the numerous decomposing processes to which it is subjected. The breathing of animals, combustion, and a thousand other operations, are constantly abstracting its oxygen, and decomposing it. The air thus decomposed or vitiated no doubt ascends in the atmosphere, and is again, by some unknown process or other, reconverted into atmospherical air. But the nature of these changes is at present concealed under an impenetrable veil.

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## SECT. II.

### OF WATER.

THAT the atmosphere contains water, has been always known. The rain and dew which so often precipitate from it, the clouds and fogs with which it is often obscured, and which deposite moisture on all bodies exposed to them, have demonstrated its existence in every age. Even when the atmosphere is perfectly transparent, water may be extracted from it in abundance by certain substances. Thus if concentrated sulphuric acid be exposed to air, it gradually attracts so much

Water of  
the atmo-  
sphere

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† Morozzo, *Jour. de Phys.* xlvii. 203.

## Book I.

Detected  
by the hy-  
grometer.

moisture, that its weight is increased more than three times: it is converted into diluted acid, from which the water may be separated by distillation. Substances which have the property of abstracting water from the atmosphere, have received the epithet of *hygroscopic*, because they point out the presence of that water. Sulphuric acid, the fixed alkalies, muriat of lime, nitrat of lime, and in general all deliquescent salts, possess this property. The greater number of animal and vegetable bodies likewise possess it. Many of them take water from moist air, but give it out again to the air when dry. These bodies augment in bulk when they receive moisture, and diminish again when they part with it. Hence some of them have been employed as *hygrometers* or measurers of the quantity of moisture contained in the air around them. This they do by means of the increase or diminution of their length, occasioned by the addition or abstraction of moisture. This change of length is precisely marked by means of an index. The most ingenious and accurate hygrometers are those of Saussure and Deluc. In the first, the substance employed to mark the moisture is a human hair, which by its contractions and dilatations is made to turn round an index. In the second, instead of a hair, a very fine thin slip of whalebone is employed. The scale is divided into 100°. The beginning of the scale indicates extreme dryness, the end of it indicates extreme moisture. It is graduated by placing it first in air made as dry as possible by means of salts, and afterwards in air saturated with moisture. This gives the extremes of the scale, and the interval between them is divided into 100 equal parts.

Since it cannot be doubted that the atmosphere al-

ways contains water, there are only two points which remain to be investigated: 1. The quantity of water which a given bulk contains; 2. The state in which that water exists in air.

Many attempts had been made to measure the quantity of water contained in air, but Saussure was the first who attained any thing like precision. This ingenious philosopher has shewn, in his *Hygrometrical Essays*, that an English cubic foot of air, when saturated with water at the temperature of  $66^{\circ}$ , contains only about 8 grains troy of that liquid, or about  $\frac{1}{87}$ th of its weight. At the temperature of  $32^{\circ}$ , a cubic foot of air can contain only 4 grains, or  $\frac{1}{134}$ th part of its weight. The quantity of water which a cubic foot of air can contain, increases 0.1109 grains for every additional degree of heat. The following TABLE exhibits the different quantities of water in grains contained in a cubic foot of air at different degrees of temperature, corresponding to the different degrees of Saussure's hygrometer. For this Table, by far the most perfect which has hitherto appeared, we are indebted to the same celebrated philosopher.

Quantity of  
water in air.

Book I.

Degrees of Hygro- meter.	TEMPERATURE*.				
	10°	21°	32°	43°	54°
40°	1.8971	1.1067	1.3653	1.6843	2.0779
45	1.0676	1.3171	1.6248	2.0045	2.4729
50	1.2197	1.5047	1.8563	2.2900	2.8251
55	1.4116	1.7414	2.1483	2.6503	3.2696
60	1.6411	2.0246	2.4976	3.0590	3.7737
65	1.9204	2.3691	2.9226	3.6055	4.4480
70	2.2277	2.7482	3.3903	4.1824	5.1596
75	2.5215	3.1107	3.8375	4.7342	5.8404
80	2.8155	3.4734	4.2850	5.2862	6.5213
85	3.1095	3.8361	4.7324	5.8381	7.2022
90	3.4035	4.1987	5.1797	6.3900	7.8831
95	3.6946	4.5578	5.6227	6.9420	8.5640
98	3.8739	4.7790	5.8956	7.2731	8.9725

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\* In this Table the cubic foot of air and the grains of water contained in it are both left in the original French measures as calculated by Saussure. The relative proportion being alone of importance, I did not think it worth while to reduce them to our standard: But in order to convert the grains in the Table into the number of grains troy contained in an English cubic foot of air, it is only necessary to multiply them by 0.6773181.



Degrees of Hygro- meter.	TEMPERATURE.			
	60°	77°	88°	100°
40°	2.5634	3.1625	3.9016	4.8134
45	2.9952	3.6952	4.5588	5.6242
50	3.4852	4.2997	5.3045	6.5442
55	4.0335	4.9761	6.1390	7.5737
60	4.6554	5.7434	7.0856	8.7415
65	5.4873	6.7697	8.3518	10.3036
70	6.3651	7.8526	9.6878	11.9518
75	7.2050	8.8888	10.9661	13.5289
80	8.0450	9.9251	12.2446	15.1062
85	8.8850	10.9614	13.5231	16.6834
90	9.7250	11.9977	14.8016	18.2607
95	10.5650	13.034	16.0800	19.8379
98	11.0690	13.6558	16.8472	20.7844

The quantity of water which air is capable of containing diminishes also as the density of that air diminishes. Saussure ascertained that air, rarefied so as only to be able to support a column of mercury 0.222 inch long, does not contain when saturated with moisture more than the 20th part of what air is capable of containing under the pressure of 28.8 inches of mercury. The following TABLE, drawn up by Mr Saussure, indicates the proportional quantity of water which a cu-

Book I.

bic foot of air is capable of containing at different densities; the density as usual being indicated by the length of the column of mercury which it is capable of balancing.

Height of Barometer.	Quantity of Water.
28.8 inches . . . . .	1.0000
25.18 . . . . .	0.9528
21.58 . . . . .	0.8899
18.38 . . . . .	0.8264
14.29 . . . . .	0.7629
10.79 . . . . .	0.6887
7.19 . . . . .	0.6230
3.59 . . . . .	0.4311
0.22 . . . . .	0.0485

Such are the quantities of water contained in air in different circumstances while that fluid retains its transparency. But as the method which Saussure took to separate all the moisture from air was to expose it to the action of very dry potass, it may be questioned whether by this process he was able to free the air altogether from moisture; and if not, it is a point of considerable consequence to determine if possible the quantity which still remains after the potass ceases to act.

Whether  
water be es-  
sential to  
air.

Some philosophers have gone so far as to suppose that water is a constituent part of air; and that therefore it cannot be wholly abstracted without destroying the air altogether, or depriving it of its elastic state. This opinion has been adopted by Dr Priestley in particular; and that philosopher has founded on it the objections which he has urged against the composition of water. The experiments of Mr Henry upon carbona-

ted hydrogen gas have demonstrated, that air, even after it has been exposed to the action of the driest salts, and those which have the strongest affinity for moisture, still retains a portion of water; but this portion is exceedingly small, and may, when the precautions of Saussure are taken, be neglected altogether without any sensible error. Mr Henry has pointed out a way of freeing some of the gases altogether from water by the action of electricity. When they are thus completely purified from water, they continue to retain their elastic form as much as ever. We may conclude, then, that air always contains water, but that water is not an ingredient so essential as to be necessary to the very existence of air in an elastic form; though a certain portion of it seems essential to render air fit to answer the different purposes for which it is intended; very dry air having exceedingly unpleasant effects upon the animal economy, as has been remarked by Saussure and other philosophers. We may conclude also, that the absolute quantity of water assigned by Saussure as contained in air, corresponding to the different degrees of his hygrometer, does not deviate very far from the truth.

With respect to the state in which water exists in air, there are only three different suppositions possible, each of which has been supported by very able philosophers. 1. Water may be dissolved in air in the same manner as a salt is held in solution by water. 2. It may be mechanically mixed with air in the state of steam or vapour; or, 3. It may be chemically combined with air, after having been converted into vapour.

State in  
which wa-  
ter exists in  
air.

1. The first of these opinions was hinted at by Dr Hooke in his *Micrographia*, and afterwards proposed by Dr Halley; but it was much more fully developed

Book I.

by Mr Le Roy of Montpelier in 1751. Dr Hamilton of Dublin made known the same theory about the same time. The phenomena in general coincide remarkably well with this theory. The quantity of water which air is capable of holding in solution is increased by every augmentation of temperature, and diminished by cold, which is precisely analogous to almost all other solvents. These analogies, and several others which will easily suggest themselves to the reader, have induced by far the greater number of philosophers to adopt this opinion.

2. The second theory ; namely, that water exists in air in the state of vapour, and merely mechanically mixed with it, has been embraced by De Luc in his last Treatise on Meteorology ; at least his reasoning appears to me to lead to that conclusion. He has proved, I think in a conclusive manner, that water, at least when it enters into the atmosphere. is always in the state of vapour, and that it evaporates independently of air altogether : but surely this is not sufficient to establish it as a fact, that the vapour, after it has mixed with air, remains merely in the state of a mechanical mixture. If it existed in that state, it would not surely be so difficult to separate it again as we find it to be.

3. The theory that water exists in the atmosphere in the state of vapour, chemically combined with air, was first advanced by Saussure and afterwards combated by Morveau and De Luc. But notwithstanding the arguments of these very ingenious and acute philosophers, I cannot help thinking it by far the most probable account of the matter that has hitherto appeared. My reasons are as follows :

It is in the  
state of va-  
pour.

In the *first* place, It cannot be doubted that the wa-



ter which exists in air, is derived originally from the waters on the surface of the earth, which are exposed to the action of the atmosphere. Accordingly we find that water, when exposed to the air, suffers a gradual diminution of bulk, and at last disappears altogether. This diminution of the water may be owing, either to its gradual solution in air, or to its conversion into vapour. The last is the common opinion, as the phenomenon is in common language ascribed to the *evaporation* of the water. When water is placed in an exhausted receiver, it diminishes in bulk even more rapidly than in the open air. In this case, as no air is present, we can only ascribe the diminution of bulk to the conversion of the water into vapour. Accordingly we find upon examination, that the receiver is actually filled with water in the state of vapour. The presence of this vapour very soon, by its elasticity, puts an end to the evaporation of the water. Now, since water disappears equally whether air be present or not, and exactly in the same manner, it is reasonable to ascribe its disappearing in both cases to the same cause. But in the exhausted receiver it is converted into vapour. Hence it is probable that it is converted into vapour also in the open air; and if so, it must exist in air in the state of vapour.

In the *second* place, If the disappearing of water exposed to the open air were owing to solution and not to evaporation, it ought certainly to disappear more rapidly when it is exposed to the action of a great quantity of air than when to a small quantity; for the quantity of any body dissolved is always proportional to the quantity of the solvent. But the very contrary is what actually takes place with respect to the water contained

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in the air. Saussure has proved that water evaporates much faster at great heights than at the surface of the earth, even when the temperature and the moisture of the air in both places are the same. By comparing a set of experiments made upon the Col-du-Geant, at the height of 11,275 feet above the level of the sea, with a similar set made at Geneva 1324 feet above the level of the sea, he ascertained, that supposing the temperature and the dryness of the air in both places the same, the quantity of water evaporated at Geneva is to that evaporated on the Col-du-Geant in the same time and same circumstances as 37 to 84, or nearly as 3 : 7. Now the air on the Col-du-Geant is about  $\frac{1}{3}$ d rarer than at Geneva ; so that a diminution of about  $\frac{1}{3}$ d in the density of the air more than doubles the rate of evaporation \*. This is precisely what ought to be the case, provided the water which disappears mixes with the air in the state of vapour only ; but the very contrary ought to hold, if the water disappeared in consequence of the solvent power of air.

In the *third* place, It has been demonstrated by Dr Black that vapour is water combined with a certain dose of caloric. Consequently when water is converted into vapour, a certain portion of caloric combines with it and disappears. If, therefore, there is the same waste of caloric whenever water passes from a liquid state and enters into the atmosphere as a component part, we have reason to conclude that it enters into the atmosphere only in the state of vapour. But it is a well known fact, that cold is always generated during spontaneous evaporation ; that is to say, that the water as it dis-

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\* Saussure's *Voyages dans les Alpes*, iv. 263.

appears carries off with it a quantity of caloric. It is well known, that when a wet body is exposed to the air, its temperature is lowered by the evaporation which takes place upon its surface. Hence in warm countries water is cooled by putting it into porous vessels, and exposing it to the air. The water penetrates through the vessels, evaporates from their surface, and carries off so much heat, as even in some cases to freeze the water in the vessel. Saussure observed that the evaporation from the surface of melting snow caused it to freeze again when the temperature of the surrounding air was  $4.5^{\circ}$  above the freezing point. Dr Black has rendered it probable that the quantity of caloric which disappears during spontaneous evaporation, is as great as that which is necessary to convert water into steam. We have a right then to conclude, that water, when it evaporates spontaneously, is always converted into vapour, and of course that it is only in that state that it enters into the atmosphere.

There may, indeed, be a small portion held in solution by air in the state of water; but this portion must be too minute to be perceptible. We know, at least, that water is capable of dissolving air, and that it always holds a portion of it in solution. It has been ascertained, that the affinity by which air is retained by water is so great, that several hours boiling are scarcely sufficient to separate it completely. Now, if water be capable of dissolving air, why may not air be capable also of dissolving water? And if so, it is reasonable to suppose that air always holds some water in solution in the state of water. But as water dissolves only a very small portion of air, and as air is a much rarer fluid than water, it is reasonable to conclude that it will dis-

## Book I.

solve proportionably less. But if this supposition be allowed, the quantity of water held in solution in air, in the state of water, must be very minute.

Let us conclude, then, with Saussure and De Luc, that almost the whole of the water which exists in the atmosphere is in the state of vapour. But we know from the nature of vapour, that whenever it comes into contact with a colder body, it is condensed again into water. This is very different from what happens to the vapour of the atmosphere; it is not deposited (except at particular times) upon colder bodies, nor indeed does it exhibit any sensible proofs of its presence. It must therefore be prevented by some cause or other from being condensed, and from exhibiting the usual properties of vapour. This cause can only be its combination with air. Hence the reason that its properties are concealed, and that it can only be separated from air by bodies which have a strong affinity for water. Hence, too, the reason that moist air is specifically lighter than dry; a fact which would be inexplicable, on the supposition that the water dissolved in air existed not in the state of steam but of water.

Quantity  
of vapour  
in the at-  
mosphere.

The water, then, which constitutes a component part of the atmosphere is chemically combined with air; but it exists in two different states. A small portion is held in solution in the state of water, but by far the greater proportion is in the state of an elastic fluid, whose specific gravity is to that of air as 10 to 12, and chemically combined with air in the same manner as one gas is combined with another. As the quantity of the water contained in the atmosphere varies considerably, it is impossible to ascertain its amount with any degree of accuracy. But let us suppose that the mean



of Saussure's hygrometer is  $70^{\circ}$ , which corresponds pretty well both with the observations of Saussure and Humbolt \*. In that case every cubic foot of air will contain at an average 3.4 grains troy of water, or  $\frac{1}{294}$ th part of its weight. According to this estimation, the average sum total of water contained in the atmosphere amounts to somewhat less than 39,703,877,421,193,939 lbs. avoirdupois. But the absolute quantity is probably considerably over-rated; for the humidity of the atmosphere diminishes very considerably as its height increases, as we learn from the experiments both of Saussure and De Luc.

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### SECT. III.

#### OF CARBONIC ACID GAS.

THE existence of carbonic acid gas as a constituent part of the atmosphere, was observed by Dr Black immediately after he had ascertained the nature of that peculiar fluid. If we expose a pure alkali or alkaline earth to the atmosphere, it is gradually converted into a carbonat by the absorption of carbonic acid gas. This fact, which had been long known, rendered the inference that carbonic acid gas existed in the atmosphere unavoidable, as soon as the difference between a pure alkali and its carbonat had been ascertained to depend upon that acid. Not only alkalies and alkaline earths

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\* *Jour. de Phys.* xlviii. 195.

## Book I.

Carbonic  
acid found  
at great  
heights.

absorb carbonic acid when exposed to the air, but several of the metallic oxides also. Hence the reason that we so often find the native oxides in the state of carbonats. Thus *rust* is always saturated with carbonic acid.

Carbonic acid gas not only forms a constituent part of the atmosphere near the surface of the earth, but at the greatest heights which the industry of man has been able to penetrate. Saussure found it at the top of Mount Blanc, the highest point of the old continent; a point covered with eternal snow, and not exposed to the influence of vegetables or animals. Lime water diluted with its own weight of distilled water, formed a pellicle on its surface after an hour and three quarters exposure to the open air on that mountain; and slips of paper moistened with pure potass, acquired the property of effervescing with acids after being exposed an hour and a half in the same place\*. Now this was at a height no less than 15,668 feet above the level of the sea. Humbolt has more lately ascertained the existence of this gas in air, brought by Mr Garnerin from a height not less than 4280 feet above the surface of the earth, to which height he had risen in an air balloon†. This fact is a sufficient proof that the presence of carbonic acid in air does not depend upon the vicinity of the earth.

Chemically  
combined  
with air.

Now as carbonic acid gas is considerably heavier than air, it could not rise to great heights in the atmosphere unless it entered into combination with the air. We are warranted, therefore, to conclude that carbonic acid is not merely mechanically mixed, but that it is che-

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\* Saussure's *Voyager*, iv. 199. † *Jour. de Phys.* xlvii. 202.

mically combined with the other constituent parts of the atmosphere. It is to the affinity which exists between carbonic acid and air that we are to ascribe the rapidity with which it disperses itself through the atmosphere, notwithstanding its great specific gravity. Fontana mixed 20,000 cubic inches of carbonic acid gas with the air of a close room, and yet half an hour after he could not discover the traces of carbonic acid in that air. Water impregnated with carbonic acid, when exposed to the air, very soon loses the whole of the combined gas. And when a phial full of carbonic acid gas is left uncorked, the gas, as Bergman first ascertained, very soon disappears, and the phial is found filled with common air.

It is owing to this strong affinity between air and carbonic acid gas that it is so difficult to detect the presence of that gas in air by the common tests. Atmospheric air does not render lime water turbid, though agitated with it ever so long, or made to pass through it in ever so great a quantity. Neither has it any effect upon the most delicate vegetable blues. The great quantity of air with which it is combined, envelopes it in such a manner that these bodies are not powerful enough to abstract it. We must employ for that purpose substances which have a very strong affinity for that acid, as the alkalies, milk of lime, &c. These substances detect its presence by acquiring the property of effervescing with acids.

The difficulty of separating this gas from air has hitherto prevented the possibility of determining with accuracy the relative quantity of it in a given bulk of air; but from the experiments which have been made, we may conclude with some degree of confidence, that

Proportion.

Book I.

it is not very different from 0.01. From the experiments of Humbolt, it appears to vary from 0.005 to 0.01. This variation will by no means appear improbable, if we consider that immense quantities of carbonic acid gas must be constantly mixing with the atmosphere, as it is formed by the respiration of animals, by combustion, and several other processes which are going on continually. The quantity, indeed, which is daily formed by these processes is so great, that at first sight it appears astonishing that it does not increase rapidly. The consequence of such an increase would be fatal, as air containing 0.1 of carbonic acid extinguishes light, and is noxious to animals. But we shall find reason afterwards to conclude, that this gas is decomposed by vegetables as rapidly as it forms.

Quantity.

On the supposition that the carbonic acid gas contained in a given bulk of air amounts to 0.01, the absolute quantity of it in the atmosphere would amount to somewhat more than 119,111,632,272,581,818 lbs. avoirdupois: an enormous quantity, which undoubtedly serves some valuable purpose in the atmosphere, though our knowledge of the changes which go on in that great laboratory is at present too imperfect to enable us even to conjecture the uses to which it may be applied



## SECT. IV.

## OF THE OTHER BODIES FOUND IN THE ATMOSPHERE.

FROM the three preceding Sections we see that the atmosphere consists chiefly of three distinct elastic fluids united together by chemical affinity; namely, air, vapour, and carbonic acid gas; differing in their proportions at different times and in different places; but that the average proportion of each is

Composi-  
tion of the  
atmosphere.

98.6 air  
1.0 carbonic acid  
0.4 water

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100.0

But besides these bodies which may be considered as the constituent parts of the atmosphere, the existence of several other bodies has been suspected in it. I do not mean in this place to include among those bodies electric matter, or the substance of clouds and fogs, and those other bodies which are considered as the active agents in the phenomena of meteorology, but to confine myself merely to those foreign bodies which have been occasionally found or suspected in air. Concerning these bodies, however, very little satisfactory is known at present, as we are not in possession of instruments sufficiently delicate to ascertain their presence. We can indeed detect several of them actually mixing with air, but what becomes of them afterwards we are unable to say.

Other bo-  
dies con-  
tained in it.

Book I.  
Hydrogen  
gas.

1. Hydrogen gas is said to have been found in air situated near the crater of volcanoes, and it is very possible that it may exist always in a very small proportion in the atmosphere; but this cannot be ascertained till some method of detecting the presence of hydrogen combined with a great proportion of air be discovered.

2. Carbonated hydrogen gas is often emitted by marshes in considerable quantities during hot weather. But its presence has never been detected in air; so that in all probability it is again decomposed by some unknown process.

3. Oxygen gas is emitted abundantly by plants during the day. We shall afterwards find reason to conclude that this is in consequence of the property which plants have of absorbing and decomposing carbonic acid gas. Now as this carbonic acid is formed at the expense of the oxygen of the atmosphere, as this oxygen is again restored to the air by the decomposition of the acid, and as the nature of atmospheric air remains unaltered, it is clear that there must be an equilibrium between these two processes; that is to say, all the carbonic acid formed by combustion must be again decomposed, and all the oxygen abstracted must be again restored. The oxygen gas which is thus continually returning to the air, by combining with it, makes its component parts always to continue in the same ratio.

4. The smoke and other bodies which are continually carried into the air by evaporation, &c. are probably soon deposited again, and cannot therefore be considered with propriety as forming parts of the atmosphere. But there is another set of bodies which are occasionally combined with air, and which, on account of the powerful action which they produce on the human bo-

dy, have attracted a great deal of attention. These are known by the name of matters of *contagion*.

That there is a difference between the atmosphere in different places, as far as respects its effects upon the human body, has been considered as an established point in all ages. Hence some places have been celebrated as healthy, and others avoided as pernicious, to the human constitution. It is well known that in pits and mines the air is often in such a state as to suffocate almost instantaneously those who attempt to breathe it. Some places are haunted by peculiar diseases. It is known that those who frequent the apartments of persons ill of certain maladies, are extremely apt to catch the infection; and in prisons and other places, where crowds of people are confined together, when diseases once commence, they are wont to make dreadful havoc. In all these cases it has been supposed that a certain noxious matter is dissolved by the air, and that it is the action of this matter which produces the mischief.

This noxious matter is in many cases readily distinguished by the peculiarly disagreeable smell which it communicates to the air. No doubt this matter differs according to the diseases which it communicates, and the substance from which it has originated. Morveau lately attempted to ascertain its nature; but he soon found the chemical tests hitherto discovered altogether insufficient for that purpose. He has put it beyond a doubt, however, that this contagious matter is of a compound nature, and that it is destroyed altogether by certain agents, particularly by those gaseous bodies which readily part with their oxygen. He exposed infected air to the action of various bodies, and he judged of the

Contagious  
matter,

## Book I.

How destroyed.

result by the effect which these bodies had in destroying the fetid smell of the air. The following is the result of his experiments.

1. Odorous bodies, such as benzoin, aromatic plants, &c. have no effect whatever.
2. Neither have the solutions of myrrh, benzoin, &c. in alcohol, though agitated in infected air.
3. Pyrolignous acid is equally inert.
4. Gunpowder, when fired in infected air, displaces a portion of it; but what remains still retains its fetid odour.
5. Sulphuric acid has no effect; sulphurous acid weakens the odour, but does not destroy it.
6. Acetous acid diminishes the odour, but its action is slow and incomplete.
7. Acetic acid acts instantly, and destroys the fetid odour of infected air completely.
8. The fumes of nitric acid, first employed by Dr Carmichael Smith, are equally efficacious.
9. Muriatic acid gas, first pointed out as a proper agent by Morveau himself, is equally effectual.
10. But the most powerful agent is oxy-muriatic acid gas, first proposed by Mr Cruickshanks, and now employed with the greatest success in the British Navy and Military hospitals.

Thus there are four substances which have the property of destroying contagious matter, and of purifying the air: but acetic acid cannot easily be obtained in sufficient quantity, and in a state of sufficient concentration to be employed with advantage. Nitric acid is attended with inconvenience, because it is almost always contaminated with nitrous gas. Muriatic acid and oxy-muriatic acid are not attended with these inconveniences; the last deserves the preference, because it acts with greater energy and rapidity. All that is necessary is to mix together two parts of salt with one part of



the black oxide of manganese, to place the mixture in an open vessel in the infected chamber, and to pour upon it two parts of sulphuric acid. The fumes of oxy-muriatic acid are immediately exhaled, fill the chamber, and destroy the contagion.

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## CHAP II.

## OF METEOROLOGY.

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THOUGH the phenomena of the weather must have at all times attracted much of the attention of mankind, because their subsistence and their comfort in a great measure depended upon them, it was not till the 17th century that any considerable progress was made in investigating the laws of meteorology. How desirous soever the ancients might have been to acquire an accurate knowledge of this science, their want of proper instruments entirely precluded them from cultivating it. By the discovery of the barometer and thermometer in the 17th century, and the invention of accurate electrometers and hygrometers in the 18th, this defect is now pretty well supplied; and philosophers are enabled to make meteorological observations with ease and accuracy. Accordingly a very great number of such observations have been collected, which have been arranged and examined from time to time by ingenious men, and consequences deduced from them, on which several dif-

Book I.

ferent theories of the weather have been built. But meteorology is a science so exceedingly difficult, that, notwithstanding the united exertions of some of the first philosophers of the age, the phenomena of the weather are still very far from being completely understood ; nor can we expect to see the veil removed, till accurate tables of observations have been obtained from every part of the world, till the atmosphere has been more completely explored, and the chemical changes which take place in it ascertained.

The changes which take place in the atmosphere demonstrate, in the clearest manner, that new combinations and decompositions are continually going on in it. On these chemical alterations the greater number of meteorological phenomena depend : they may be considered as the result of the mutual action of the different component parts of the atmosphere ; and would admit of an easy explanation, if we were thoroughly acquainted with all those substances, and with the chemical laws which govern their action. The most important meteorological phenomena are, 1. The changes which take place in the weight of the atmosphere ; 2. The changes which take place in its temperature ; 3. The fogs, clouds, and rain which so often precipitate from it ; 4. The violent agitation into which it is often thrown ; and, 5. The electric phenomena which sometimes accompany or occasion these precipitations and agitations. The consideration of these subjects shall occupy the five following Sections.

## SECT. I.

## OF CHANGES IN THE WEIGHT OF THE ATMOSPHERE.

WE have seen in the last Chapter, that the barometer indicates to us the weight of a column of air, extending to the top of the atmosphere, and whose base is equal to that of the mercury. At the level of the sea, where the column of air is longest, the mean height of the barometer is 30 inches. This Sir George Shuckburgh found to be the case in the Mediterranean and the Channel, in the temperature of  $55^{\circ}$  and  $60^{\circ}$ ; Mr Bouguer, on the coast of Peru, in the temperature of  $84^{\circ}$ ; and Lord Mulgrave, in latitude  $80^{\circ}$ . The mean height of the barometer is less the higher any place is situated above the level of the sea, because the column of air which supports the mercury is the shorter. The barometer has accordingly been used for measuring heights. But if a barometer be allowed to remain in one place, the mercury does not remain stationary; sometimes it rises and at other times falls, varying to the extent of several inches; of course the weight of the air which balances the mercury must be subject to the same changes. Hence we learn that the air in the same place is sometimes light and at other times heavy; differences which must be owing to changes in its quantity. The barometer then informs us, that the quantity of air above any spot is liable to continual alterations. Consequently either the air accumulates in particular spots, while it partially abandons others; or

Height of  
the baro-  
meter on  
the sea  
shore.

Variation.

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part of the atmosphere must be alternately abstracted altogether, and restored again by some constant though apparently irregular process.

Between the tropics the variations of the barometer are exceedingly small; and it is remarkable, that in that part of the world it does not descend above half as much for every 200 feet of elevation as it does beyond the tropics ||. In the torrid zone, too, the barometer is elevated about two thirds of a line twice every day; and this elevation happens at the same time with the tides of the sea ¶.

Annual  
range.

As the latitude advances towards the poles, the range of the barometer gradually increases, till at last it amounts to two or three inches. This gradual increase will appear from the following Table:

TABLE of the Range of the Barometer.

Latitude.	Places.	Range of the Barometer.	
		Greatest.	Annual.
0°	Peru	0.29 *	—
22 23	Calcutta	0.77 †	—
40 55	Naples	1.00 *	—
51 8	Dover	2.47 §	1.80
53 13	Middlewick	3.00 §	1.94
53 23	Liverpool	2.89 §	1.96
59 56	Petersburgh	3.45 ‡	2.77

|| M. Cassan, *Jour. de Phys.* April 1790, p. 268.

¶ Ibid.

\* Kirwan, *Irish Trans.* vol. iii. p. 47.† *Asiatic Researches*, vol. ii. Appendix.§ *Manchester Trans.* vol. iv.‡ *Edinburgh Trans.* vol. ii. p. 229.



In North America, however, the range of the barometer is a great deal less than in the corresponding European latitudes. In Virginia, for instance, it never exceeds 1.1 \*.

The range of the barometer is greater at the level of the sea than on the mountains, and in the same degree of latitude the extent of the range is in the inverse ratio of the height of the place above the level of the sea.

From a table published by Mr Cotte in the *Journal de Physique* †, it seems exceedingly probable that the barometer has always a tendency to rise from the morning to the evening; and that this tendency is greatest between two o'clock in the afternoon and nine at night, at which hour the greatest elevation takes place; that the elevation of nine o'clock differs from that of two by  $\frac{4}{12}$ ths, while that at two differs from the morning elevation only by  $\frac{1}{12}$ th; and that in certain climates the greatest elevation takes place at two o'clock. The following is a part of the Table on which these observations are founded, reduced to the English standard.

Diurnal  
range.

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\* *Trans. Philadel.* vol. ii. p. 142.

† *Aug.* 1790, p. 110.

Places.	Years of observation	Mean height of Barometer.			
		Morning.	Noon.	Evening.	Year.
Arles	6	29.9347	29.9347	29.9413	29.9347
Arras	6	29.6683	29.6683	29.6832	29.6758
Bourdeaux	11	29.7212	29.8385	29.8385	29.8385
Cambray	13	29.8756	29.8682	29.8756	29.8756
Chinon	12	29.7719	29.7795	29.8001	29.7869
Dunkirk	8	29.9199	29.9347	29.9347	29.9273
Hagenau	10	29.5648	29.5648	29.5741	29.5648
Laon	7	29.3354	29.3206	29.3429	29.3354
Lisle	6	29.9165	29.9274	29.9347	29.9077
Mayenne	7	29.7172	29.7056	29.7127	29.7127
Manheim	5	29.6167	29.6018	29.6167	29.6093
Montmorenci	22	29.6536	29.6536	29.6610	29.6536
Mulhausen	7	29.1873	29.1800	29.1873	29.1873
Obernheim	12	29.4834	29.4665	29.4764	29.4764
Paris	67	29.8902	29.8607	29.8756	29.8756
Poitiers	12	29.7276	29.7276	29.7276	29.7276
Rouen	11	29.8607	29.8535	29.8535	29.8535
Rome	3	29.8607	29.8460	29.8756	29.8607
St Maurice le Gerard	10	29.8016	29.8016	29.8090	29.8016
Troyes	10	29.6885	29.6979	29.6885	29.6885

The range of the barometer is greater in winter than in summer. Thus at York the mean range of the barometer, during October, November, December, January, February, March, of the year 1774, was 1.42; and for the six summer months 1.016\*.

In serene and settled weather it is generally high; and low in calm weather, when the air is inclined to rain; it sinks on high winds, rises highest on easterly and northerly winds, and sinks when the wind blows

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\* *Manchester Trans.* vol. iv. p. 543.

from the south \*. At Calcutta †, it is always highest when the wind blows from the north-west and north, and lowest when it blows from the south-east.

The barometer falls suddenly before tempests, and undergoes great oscillations during their continuance. Mr Copland ‡ of Dumfries has remarked, that a high barometer is attended with a temperature above, and a low barometer with one below, the monthly mean.

Such are the phenomena respecting the variations of the barometer, as far as they can be reduced under general heads. Various attempts have been made to explain them, but hitherto without any great degree of success. The theory of Mr Kirwan appears to me by far the most plausible, though it is not sufficient to explain all the facts. The following observations may be considered as a kind of abstract of his theory, except in one or two instances.

It is evident that the density of the atmosphere is least at the equator and greatest at the poles; for at the equator the centrifugal force, the distance from the centre of the earth, and the heat, all of which tend to diminish the density of the air, are at their maximum, while at the pole they are at their minimum. The mean height of the barometer at the level of the sea, all over the globe, is 30 inches; the weight of the atmosphere, therefore, is the same all over the globe. The weight of the atmosphere depends on its density and height: where the density of the atmosphere is greatest, its height must be least; and, on the contrary, where its density is least, its height must be greatest. The height

Atmo-  
sphere  
highest at  
the equa-  
tor.

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\* Dr Halley.

† *Asiatic Researches*, vol. ii. Appendix.

‡ *Manchester Trans.*, vol. iv.

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of the atmosphere, therefore, must be greatest at the equator, and least at the poles; and it must decrease gradually between the equator and the poles, so that its upper surface will resemble two inclined planes, meeting above the equator their highest part \*.

During summer, when the sun is in our hemisphere, the mean heat between the equator and the pole does not differ so much as in winter. Indeed the heat of northern countries at that time equals the heat of the torrid zone: thus in Russia, during July and August, the thermometer rises to  $85^{\circ}$  †. Hence the rarity of the atmosphere at the pole, and consequently its height, will be increased. The upper surface of the atmosphere, therefore, in the northern hemisphere will be less inclined; while that of the southern hemisphere, from contrary causes, will be much more inclined. The very reverse will take place during our winter.

The density of the atmosphere depends in a great measure on the pressure of the superincumbent column; and therefore decreases, according to the height, as the pressure of the superincumbent column constantly decreases. But the density of the atmosphere in the torrid zone will not decrease so fast as in the temperate and frigid zones; because its column is longer, and because there is a greater proportion of air in the higher part of this column. This accounts for the observation of Mr Cassan, that the barometer only sinks half as much for every 200 feet of elevation in the torrid as in the temperate zones ‡. The density of the atmosphere at

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\* Kirwan, *Irish Trans.* vol. ii. p. 43, &c.

† Dr Guthrie, *Edin. Trans.* vol. ii. p. 229.

‡ Should it not be examined whether the number of parts which the



the equator, therefore, though at the surface of the earth it is less, must at a certain height equal, and at a still greater surpass, the density of the atmosphere in the temperate zones and at the poles.

A current of air is constantly ascending at the equator, and part of it at least reaches and continues in the higher parts of the atmosphere. From the fluidity of air, it is evident that it cannot accumulate above the equator, but must roll down the inclined plane which the upper surface of the atmosphere assumes towards the poles. As the surface of the atmosphere of the northern hemisphere is more inclined during our winter than that of the southern hemisphere, a greater quantity of the equatorial current of air must flow over upon the northern than upon the southern atmosphere; so that the quantity of our atmosphere will be greater during winter than that of the southern hemisphere: but during summer the very reverse will take place. Hence the greatest mercurial heights take place during winter, and the range of the barometer is less in summer than in winter.

Hence the air, as it ascends, rolls towards the coldest pole.

The density of the atmosphere is in a great measure regulated by the heat of the place: wherever the cold is greatest, there the density of the atmosphere will be greatest, and its column shortest. High countries, and ranges of lofty mountains, the tops of which are covered with snow the greatest part of the year, must be much colder than other places situated in the same degree of latitude, and consequently the column of air over them much shorter. The current of superior air

Air accumulates over cold places.

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mercury sinks for every 200 feet of elevation be not proportioned to the latitude of the place?

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will linger and accumulate over these places in its passage towards the poles, and thus occasion an irregularity in its motion, which will produce a similar irregularity in the barometer. Such accumulations will be formed over the north-western parts of Asia and over North America: hence the barometer usually stands higher, and varies less there than in Europe. Accumulations are also formed upon the Pyrenees, the Alps, the mountains of Africa, Turkey in Europe, Tartary, and Tibet. When these accumulations have gone on for some time, the density of the air becomes too great to be balanced by the surrounding atmosphere; it rushes down on the neighbouring countries, and produces cold winds which raise the barometer. Hence the rise of the barometer which generally attends north-east winds in Europe, as they proceed from accumulations in the north-west of Asia, or about the pole; hence, too, the north-west wind from the mountains of Tibet raises the barometer at Calcutta.

It is probable that considerable quantities of air are occasionally destroyed in the polar regions. When this happens, the atmosphere to the south rushes in to fill up the void. Hence south-west winds take place, and the barometer falls.

As the mean heat of our hemisphere differs in different years, the density of the atmosphere, and consequently the quantity of equatorial air which flows towards the poles, must also be variable. Hence the range of the barometer is different in different years. Does this range correspond to the mean annual heat; that is to say, is the range greatest when the heat is least, and least when the heat is greatest? In some years greater accumulations than usual take place in the

mountainous parts in the south of Europe and Asia, owing, perhaps, to earlier falls of snow, or to the rays of the sun having been excluded by long continued fogs. When this takes place, the atmosphere in the polar regions will be proportionably lighter. Hence the prevalence of southerly winds during some winters more than others.

As the heat in the torrid zone never differs much, the density, and consequently the height of the atmosphere, will not vary much. Hence the range of the barometer within the tropics is comparatively small; and it increases gradually as we approach the poles, because the difference of the temperature, and consequently of the density, of the atmosphere increases with the latitude.

Why the  
barometer  
varies little  
between  
the tropics

The diurnal elevation of the barometer in the torrid zone corresponding to the tides, observed by Mr Cassan and others, must be owing to the influence of the moon on the atmosphere. This influence, notwithstanding the ingenious attempts of D'Alembert and several other philosophers, seems altogether inadequate to account for the various phenomena of the winds. It is not so easy to account for the tendency which the barometer has to rise as the day advances, which seems to be established by Mr Cotte's table. Perhaps it may be accounted for by the additional quantity of vapour added to the atmosphere, which, by increasing the quantity of the atmosphere, may possibly be adequate to produce the effect.

The falls of the barometer which precede, and the oscillations which accompany, violent storms and hurricanes, show us that these phenomena are produced by very great rarefactions, or perhaps destruction of

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air, in particular parts of the atmosphere. The falls of the barometer, too, that accompany winds proceed from the same cause.

The falling of the barometer which generally precedes rain, remains still to be accounted for ; but we know too little about the causes by which rain is produced to be able to account for it in a satisfactory manner.

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## SECT. II.

### OF THE TEMPERATURE OF THE AIR.

**T**HOUGH there is a considerable difference in every part of the world between the temperature of the atmosphere in summer and in winter ; though in the same season the temperature of almost every day, and even every hour, differs from that which precedes and follows it ; though the heat varies continually in the most irregular and seemingly capricious manner—still there is a certain mean temperature in every climate, which the atmosphere has always a tendency to observe, and which it neither exceeds nor comes short of beyond a certain number of degrees. What this temperature is, may be known by taking the mean of tables of observations kept for a number of years ; and our knowledge of it must be the more accurate the greater the number of observations is.

Method of  
ascertain-  
ing the  
mean an-  
nual tem-  
perature.

The mean annual temperature is greatest at the equator (or at least a degree or two on the north side of it), and it diminishes gradually towards the poles,



where it is least. This diminution takes place in arithmetical progression; or, to speak more properly, the annual temperature of all the latitudes are arithmetical means between the mean annual temperature of the equator and the pole. This was first discovered by Mr Mayer; and by means of an equation which he founded on it, but rendered considerably plainer and simpler, Mr Kirwan has calculated the mean annual temperature of every degree of latitude between the equator and the pole. He proceeded on the following principle. Let the mean annual heat at the equator be  $m$ , and at the pole  $m - n$ ; put  $\phi$  for any other latitude; the mean annual temperature of that latitude will be  $m - n \times \sin. \phi^2$ . If therefore the temperature of any two latitudes be known, the value of  $m$  and  $n$  may be found. Now the temperature of north lat.  $40^\circ$  has been found by the best observations to be  $62.1^\circ$ , and that of lat.  $50^\circ$ ,  $52.9^\circ$ . The square of the sine of  $40^\circ$  is nearly  $0.419$ , and the square of the sine of  $50^\circ$  is nearly  $0.586$ . Therefore

$$m - 0.41 n = 62.1, \text{ and}$$

$$m - 0.58 n = 52.9; \text{ therefore}$$

$$62.1 + 0.41 n = 52.9 + 0.58 n, \text{ as each}$$

of them, from the two first equations, is equal to  $m$ . From this last equation the value of  $n$  is found to be  $53$  nearly; and  $m$  is nearly equal to  $84$ . The mean temperature of the equator therefore is  $84^\circ$ , and that of the pole  $31^\circ$ . To find the mean temperature for every other latitude, we have only to find 88 arithmetical means between  $84$  and  $31$ . In this manner Mr Kirwan calculated the following TABLE:

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TABLE of the Mean Annual Temperature of the Standard Situation in every Latitude.

Lat.	Temper.	Lat.	Temper.	Lat.	Temper.
90	31.	61	43.5	32	69.1
89	31.04	60	44.3	31	69.9
88	31.10	59	45.09	30	70.7
87	31.14	58	45.8	29	71.5
86	31.2	57	46.7	28	72.3
85	31.4	56	47.5	27	72.8
84	31.5	55	48.4	26	73.8
83	31.7	54	49.2	25	74.5
82	32.	53	50.2	24	75.4
81	32.2	52	51.1	23	75.9
80	32.6	51	52.4	22	76.5
79	32.9	50	52.9	21	77.2
78	33.2	49	53.8	20	77.8
77	33.7	48	54.7	19	78.3
76	34.1	47	55.6	18	78.9
75	34.5	46	56.4	17	79.4
74	35.	45	57.5	16	79.9
73	35.5	44	58.4	15	80.4
72	36.	43	59.4	14	80.8
71	36.6	42	60.3	13	81.3
70	37.2	41	61.2	12	81.7
69	37.8	40	62.	11	82.
68	38.4	39	63.	10	82.3
67	39.1	38	63.9	9	82.7
66	39.7	37	64.8	8	82.9
65	40.4	36	65.7	7	83.2
64	41.2	35	66.6	6	83.4
63	41.9	34	67.4	5	83.6
62	42.7	33	68.3	0	84

This Table, however, only answers for the temperature of the atmosphere of the ocean. It was calculated for that part of the Atlantic Ocean which lies between the 80th degree of northern and the 45th of southern

latitude, and extends westwards as far as the Gulf-stream, and to within a few leagues of the coast of America; and for all that part of the Pacific Ocean reaching from lat.  $45^{\circ}$  north to lat.  $40^{\circ}$  south, from the 20th to the 275th degree of longitude east of London. This part of the ocean Mr Kirwan calls *the standard*; the rest of the ocean is subject to anomalies which will be afterwards mentioned.

Mr Kirwan has also calculated the mean monthly temperature of the standard ocean. The principles on which he went were these: The mean temperature of April seems to approach very nearly to the mean annual temperature; and as far as heat depends on the action of the solar rays, the mean heat of every month is as the mean altitude of the sun, or rather as the sine of the sun's altitude. The mean heat of April, therefore, and the sine of the sun's altitude being given, the mean heat of May is found in this manner: As the sine of the sun's mean altitude in April is to the mean heat of April, so is the sine of the sun's mean altitude in May to the mean heat of May. In the same manner the mean heats of June, July, and August, are found; but the rule would give the temperature of the succeeding months too low, because it does not take in the heat derived from the earth, which possesses a degree of heat nearly equal to the mean annual temperature. The real temperature of these months therefore must be looked upon as an arithmetical mean between the astronomical and terrestrial heats. Thus in latitude  $51^{\circ}$ , the astronomical heat of the month of September is  $44.6^{\circ}$ , and the mean annual heat is  $52.4^{\circ}$ ; therefore the real heat of this month should be  $\frac{44.6 + 52.4}{2}$

Mean  
monthly  
tempera-  
ture.

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= 48.5. Mr Kirwan, however, after going through a tedious calculation, found the results to agree so ill with observations, that he drew up the following TABLE, partly from principles and partly by studying a variety of sea journals.

TABLE of the Monthly Mean Temperature of the Standard from lat. 80° to lat. 10°.

Lat.	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°
Jan.	22.	22.5	23.	23.5	24.	24.5	25.	25.5	26.	26.5
Feb.	23.	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.
Mar.	27.	27.5	28.	28.5	29.	29.5	30.	30.5	31.	31.5
Apr.	32.6	32.9	33.2	33.7	34.1	34.5	35.	35.5	36.	36.6
May	36.5	36.5	37.	37.5	38.	38.5	39.	39.5	40.	40.5
June	51.	51.	51.5	52.	52.	52.	52.5	53.	53.5	54.
July	50.	50.	50.5	51.	51.	51.	51.5	52.	52.5	53.
Aug.	39.5	40.	41.	41.5	42.	42.5	43.	43.5	44.	44.5
Sept.	33.5	34.	34.5	35.	35.5	36.	36.5	37.	38.	38.5
Oct.	28.5	29.	29.5	30.	30.5	31.	31.5	32.	32.5	33.
Nov.	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.	27.5
Dec.	22.5	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.

Lat.	70°	69°	68°	67°	66°	65°	64°	63°	62°	61°
Jan.	27.	27.5	27.5	28.	28.	28.	29.	30.	31.	32.
Feb.	27.5	28.	28.	28.5	29.	30.	31.	32.	33.	34.
Mar.	32.	32.5	33.	33.5	34.	35.	36.	37.	38.	39.
Apr.	37.2	37.8	38.4	39.1	39.7	40.4	41.2	41.9	42.7	43.5
May	41.	41.5	42.	42.5	43.	44.	45.	46.	47.	48.
June	54.	54.5	54.5	54.5	55.	55.	55.5	55.5	56.	56.
July	53.5	53.5	53.5	54.	54.5	54.5	55.	55.	55.5	55.5
Aug.	45.	45.5	46.	47.	48.	48.5	49.	50.	51.	52.
Sept.	39.	39.5	40.	41.	42.	43.	44.	45.	46.	47.
Oct.	33.5	34.	34.	35.	36.	37.	37.5	38.	39.	40.
Nov.	28.	28.5	29.	30.	31.	32.	32.5	33.	34.	35.
Dec.	27.5	28.	28.	29.	30.	30.5	31.	31.	32.	33.

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Lat.	60	59°	58°	57°	56°	55°	54°	53°	52°	51°
Jan.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.
Feb.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.
Mar.	40.	41.	42.	43.	44.	45.	46.	48.	49.	50.
Apr.	44.3	45.09	45.8	46.7	47.5	48.4	49.2	50.2	51.1	52.4
May	49.	50.	51.	52.	53.	54.	55.	56.	57.	58.
June	56.	56.5	57.	57.	57.5	58.	58.5	59.	59.	60.
July	56.	56.5	57.	57.5	58.	59.	60.	61.	62.	63.
Aug.	53.	54.	55.	56.	57.	58.	59.	60.	61.	62.
Sept.	48.	49.	50.	51.	52.	53.	54.	55.	56.	57.
Oct.	41.	42.	43.	44.	45.	46.	47.	48.	49.	50.
Nov.	36.	37.	38.	39.	40.	41.	42.	43.	44.5	46.
Dec.	34.	35.	36.	37.	38.	39.	40.	41.	42.	44.

Lat.	50°	49°	48°	47°	46°	45°	44°	43°	42°	41°
Jan.	42.5	43.5	43.	42.5	44.	44.5	45.	45.5	46.	46.5
Feb.	44.5	44.5	45.	45.5	46.	46.5	47.	48.	49.	50.
Mar.	50.5	51.	52.5	53.	53.5	54.5	55.5	56.5	58.5	59.5
Apr.	52.9	53.8	54.7	55.6	56.4	57.5	58.4	59.4	60.3	61.2
May	58.5	59.	60.1	61.	62.	63.	64.	65.	66.	67.
June	61.	62.	63.	64.	65.	66.	67.	68.	69.	70.
July	63.5	64.	65.	66.	67.	68.	69.	69.5	70.	70.
Aug.	63.5	64.	65.	66.	67.	68.	69.	69.5	70.	70.
Sept.	58.5	59.	60.	61.	62.	63.	64.	66.	68.	69.5
Oct.	50.5	51.	52.	53.	54.	55.	56.	57.	58.	59.
Nov.	46.5	47.	48.	49.	50.	51.	52.	53.	54.	55.
Dec.	44.5	45.	46.	47.	48.	49.	50.	51.	52.	53.

Lat.	40°	39°	38°	37°	36°	35°	34°	33°	32°	31°
Jan.	49.5	51.	52.	53.5	55.	56.5	59.5	63.	63.	63.
Feb.	53.	56.5	58.	60.	61.	62.	63.	64.5	66.	67.
Mar.	60.	60.5	61.	62.	63.	64.	65.	66.5	67.5	68.5
Apr.	62.1	63.	63.9	64.8	65.7	66.6	67.4	68.3	69.1	69.9
May	68.	69.	70.	70.5	71.	71.5	72.	72.5	73.	73.
June	70.5	71.	71.	71.	71.5	71.5	72.	72.5	73.	73.
July	71.	71.	72.	72.	72.5	72.5	72.5	72.5	73.	73.
Aug.	71.	71.	72.	72.	72.5	72.5	72.5	72.5	73.	73.
Sept.	70.5	71.	71.5	72.	72.5	72.5	72.5	72.5	73.	73.
Oct.	60.	61.	62.	63.	64.	65.	66.	67.5	68.5	69.5
Nov.	56.	57.	58.	59.	60.	61.	62.	63.	64.5	65.5
Dec.	54.	55.	56.	57.	58.	59.	60.	61.	62.5	63.5



Book I.	Lat.	30°	29°	28°	27°	26°	25°	24°	23°	22°	21°	20°
Jan.	63.5	63.5	63.5	64.	64.5	65.5	67.	68.	69.	71.	72.	
Feb.	68.5	68.5	69.5	69.5	70.5	71.	72.	72.	72.5	74.	75.	
Mar.	69.5	71.	72.	72.5	73.	73.5	74.5	75.	75.5	76.	77.	
Apr.	70.7	71.5	72.3	72.8	73.8	74.5	75.4	75.9	76.5	77.2	77.8	
May	73.5	74.5	75.5	76.	76.5	77.5	78.	78.5	79.5	80.	80.5	
June	73.5	74.5	75.5	76.	76.5	78.	78.5	79.	79.5	80.	80.5	
July	73.5	74.5	75.5	76.	76.5	78.	78.5	79.	79.5	80.	80.5	
Aug.	73.5	74.5	75.5	76.	76.5	78.	78.5	79.	79.5	80.	80.5	
Sept.	73.5	74.	75.5	76.	76.5	77.5	78.	78.5	79.	79.5	80.	
Oct.	70.5	71.	72.5	72.5	73.	73.5	74.5	75.	75.5	77.	78.	
Nov.	66.5	68.	69.	69.5	71.5	72.	73.5	74.	74.5	75.	75.5	
Dec.	64.5	66.	67.	67.5	68.5	69.5	70.	71.	71.5	72.	72.5	

Lat.	19	18°	17°	16°	15°	14°	13°	12°	11°	10°
Jan.	72.5	73.	73.5	74.	74.5	75.	76.	76.5	77.	77.5
Feb.	76.	76.5	77.	77.5	78.	78.5	79.	79.5	79.8	80.
Mar.	77.5	78.	78.5	79.	79.5	80.	80.8	81.	81.5	81.8
Apr.	78.3	78.9	79.4	79.9	80.4	80.8	81.3	81.7	82.	82.3
May	81.	81.5	82.	82.5	83.	83.	83.5	84.	84.	84.3
June	81.5	82.	82.5	83.	83.5	83.8	84.	84.3	84.6	84.8
July	81.5	82.	82.5	83.	83.5	83.8	84.	84.3	84.6	84.8
Aug.	81.5	82.	82.5	83.	83.5	83.8	84.	84.3	84.6	84.8
Sept.	81.	81.5	82.	82.5	83.	83.	83.5	84.	84.3	84.6
Oct.	79.	80.	81.	81.5	82.	82.5	83.	83.5	83.8	84.
Nov.	76.	77.	78.	78.5	79.	79.5	80.	80.5	80.8	81.
Dec.	73.	74.	75.	75.5	76.	76.5	77.	77.5	78.	78.5

From this Table it appears that January is the coldest month in every latitude, and that July is the warmest month in all latitudes above 48°. In lower latitudes August is generally warmest. The difference between the hottest and coldest months increases in proportion to the distance from the equator. Every habitable latitude enjoys a mean heat of 60° for at least two months; this heat seems necessary for the production of corn. Within ten degrees of the poles, the temperatures dif-

fer very little, neither do they differ much within ten degrees of the equator; the temperature of different years differ very little near the equator, but they differ more and more as the latitudes approach the poles.

The temperature of the earth at the level of the sea is the same with that of the standard ocean; but this temperature gradually diminishes as we ascend above that level till, at a certain height, we arrive at the region of perpetual congelation. This region varies in height according to the latitude of the place; it is highest at the equator, and descends gradually nearer the earth as we approach the poles. It varies also according to the season, being highest in summer and lowest in winter. M. Bouguer found the cold on the top of Pinchinca, one of the Andes, to extend from seven to nine degrees below the freezing point every morning immediately before sun-rise. He concluded, therefore, that the mean height of the *term of congelation* (the place where it first freezes during some part of the day all the year round) between the tropics was 15,577 feet above the level of the sea; but in lat.  $28^{\circ}$  he placed it in summer at the height of 13,440 feet. Now, if we take the difference between the temperature of the equator and the freezing point, it is evident that it will bear the same proportion to the term of congelation at the equator that the difference between the mean temperature of any other degree of latitude and the freezing point bears to the term of congelation in that latitude. Thus the mean heat of the equator being  $84^{\circ}$ , the difference between it and 32 is 52; the mean heat of lat.  $28^{\circ}$  is  $72.3^{\circ}$ , the difference between which and 32 is 40.3: Their  $52 : 15577 :: 40.3 : 12072$ . In this manner Mr Kirwan calculated the following Table:

Tempera-  
ture of dif-  
ferent  
heights  
above the  
sea.

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Mean height of the  
Term of Congelation.

LAT.	FEET.
0 . . . . .	15577
5 . . . . .	15457
10 . . . . .	15067
15 . . . . .	14498
20 . . . . .	13719
25 . . . . .	13030
30 . . . . .	11592
35 . . . . .	10664
40 . . . . .	9016
45 . . . . .	7658
50 . . . . .	6260
55 . . . . .	4912
60 . . . . .	3684
65 . . . . .	2516
70 . . . . .	1557
75 . . . . .	748
80 . . . . .	120

If the elevation of a country above the level of the sea proceeds at a greater rate than six feet *per* mile, we must, according to Mr Kirwan \*, for every 200 feet of elevation diminish the annual temperature of the standard in that latitude as follows. If the elevation be at the rate of

6 feet *per* mile,  $\frac{1}{4}$  of a degree

7 feet . . . . .  $\frac{1}{3}$

13 feet . . . . .  $\frac{4}{10}$

15 or upwards .  $\frac{1}{2}$

Tempera-  
ture at a  
distance  
from the  
sea.

According to him † also, for every 50 miles distance from the standard ocean, the mean annual temperature in

\* *Temperature of Latitudes*, p. 43.

† *Ibid.* p. 45.

different latitudes is to be depressed or raised nearly at the following rate: Chap. II.

From lat.  $70^{\circ}$  to lat  $35^{\circ}$  depressed  $\frac{1}{3}$  of a degree

35 . . . . .	$\frac{1}{8}$
30 . . . . .	0
25 raised . . . . .	$\frac{1}{5}$
20 . . . . .	$\frac{1}{2}$
10 . . . . .	$1^{\circ}$

The cause of the heat of the atmosphere is evidently the sun's rays; this has been observed and acknowledged in all ages. The heat which they produce is less according as they fall more obliquely; hence the temperature constantly diminishes from the equator to the pole, because their obliquity constantly increases with the latitude. But if the heat depended on the solar rays alone, it would disappear in the polar regions during winter when the sun ceases to rise. This, however, is by no means the case; the mean temperature, even at the pole, is  $31^{\circ}$ ; and we find within the arctic circle as hot weather as under the equator. The reason of this is, that the sun's rays heat the earth considerably during summer: this heat it retains and gives out slowly during winter, and thus moderates the violence of the cold; and summer returns before the earth has time to be cooled down beyond a certain degree. This is the reason that the coldest weather does not take place at the winter solstice, but some time after, when the temperature of the earth is lowest; and that the greatest heat takes place also some considerable time after the summer solstice, because then the temperature of the earth is highest. For pure air is not heated by the solar rays which pass through it, but acquires slowly the temperature of the earth with which it is in contact.

Variation  
in tempera-  
ture ex-  
plained.

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This is the reason why the temperature decreases according to the elevation above the level of the sea.

Since the atmosphere is heated by contact with the superficies of the earth, its temperature must depend upon the capacity of that superficies for receiving and transmitting heat. Now this capacity differs very much in land and water. Land, especially when dry, receives heat with great readiness, but transmits it through its own substance very slowly. Dr Hailes found, that in 1724, when the air and surface of the earth were both at  $88^{\circ}$ , a thermometer placed only two inches below the surface stood at  $85^{\circ}$ ; another 16 inches below the surface, at  $70^{\circ}$ ; and another 24 inches deep, at  $68^{\circ}$ . The two last mentioned thermometers retained the same temperature till the end of the month, though the temperature of the air frequently varied, and then fell only to  $63^{\circ}$  or  $61^{\circ}$ . The earth, at about 80 or 90 feet below its surface, constantly retains the same temperature; and this is nearly equal to the mean annual heat of the country. Hence the mean annual temperature of any country may be found out pretty accurately by examining the heat of deep wells or springs. Water, on the contrary, receives heat slowly, on account of its transparency; but what it does receive, is very quickly carried through the whole mass.

Land is often heated and cooled to a much greater degree than sea is. Dr Raymond often found the earth in the neighbourhood of Marseilles heated to  $170^{\circ}$ , but he never found the sea above  $77^{\circ}$ : in winter the earth was often cooled down to  $14^{\circ}$ , but the sea never lower than  $45^{\circ}$ . The sea atmosphere, therefore, ought to preserve a much more uniform temperature than the land atmosphere; and we find this in fact to be the



case. The cause of the greater equability of water than land is evident. In summer the surface of the sea is constantly cooled down by evaporation; and in winter, whenever the surface is cooled, it descends to the bottom from its increased gravity, while its place is supplied by warmer water. This process goes on continually, and the winter is over before the atmosphere has been able to cool down the water beyond a certain degree.

These observations will enable us to explain the difference which takes place between the annual temperature of the atmosphere above the ocean and that of places at some considerable distance from it. As the sea is never heated so highly as the land, the mean summer temperature at sea may be considered all over the world as lower than on land. During winter, when the power of the sun's rays in a great measure ceases, the sea gives out heat to the air much more readily than the earth: the mean winter temperature therefore at sea is higher than on land; and in cold countries the difference is so great, that it more than counterbalances the difference which takes place in summer; so that in high latitudes the mean annual temperature ought to be greater at sea than on land. Accordingly from lat.  $70^{\circ}$  to  $35^{\circ}$ , to find the temperature of a place, the standard temperature for the same latitude ought, according to Mr Kirwan, to be depressed  $\frac{1}{4}$  of a degree for every 50 miles distance; for the cold which takes place in winter always increases in proportion to the distance from the standard. At a less distance than 50 miles, the temperatures of land and sea are so blended together by sea and land winds, that there is little difference in the annual mean. In lower latitudes than  $30^{\circ}$ , the

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rays of the sun, even in winter, retain considerable power; the surface of the earth is never cooled very low, consequently the difference between the annual temperatures of the sea and land becomes less. As we approach nearer to the equator, the power of the solar rays during winter increases so that the mean winter temperature of the land atmosphere approaches nearer and nearer to that of the sea, till at last at the equator it equals it. After we pass lat.  $30^{\circ}$ , therefore, the mean annual land temperature gradually exceeds that of the sea more and more, till at the equator it exceeds it a degree for every 50 miles distance.

## Exceptions.

Such then, in general, is the method of finding the mean annual temperature over the globe. There are, however, several exceptions to these general rules, which come now to be mentioned.

1. North  
Pacific  
Ocean.

That part of the Pacific Ocean which lies between north lat.  $52^{\circ}$  and  $66^{\circ}$  is no broader at its northern extremity than 42 miles, and at its southern extremity than 1300 miles: it is reasonable to suppose, therefore, that its temperature will be considerably influenced by the surrounding land, which consists of ranges of mountains covered a great part of the year with snow; and there are besides a great many high, and consequently cold, islands scattered through it. For these reasons Mr Kirwan concludes, that its temperature is at least 4 or 5 degrees below the standard. But we are not yet furnished with a sufficient number of observations to determine this with accuracy.

2. Southern  
hemisphere.

It is the general opinion that the southern hemisphere, beyond the 40th degree of latitude, is considerably colder than the corresponding parts of the north-

ern hemisphere. The probable cause of which will be assigned in the Fourth Section of this Chapter.

Small seas surrounded with land, at least in temperate and cold climates, are generally warmer in summer and colder in winter than the standard ocean, because they are a good deal influenced by the temperature of the land. The Gulph of Bothnia, for instance, is for the most part frozen in winter; but in summer it is sometimes heated to  $70^{\circ}$ ; a degree of heat never to be found in the opposite part of the Atlantic\*. The German Sea is above three degrees colder in winter, and five degrees warmer in summer than the Atlantic†. The Mediterranean Sea is, for the greater part of its extent, warmer both in summer and winter than the Atlantic, which therefore flows into it. The Black Sea is colder than the Mediterranean, and flows into it‡.

3. Small  
seas.

The eastern parts of North America are much colder than the opposite coast of Europe, and fall short of the *standard* by about  $10^{\circ}$  or  $12^{\circ}$ , as appears from American Meteorological Tables. The causes of this remarkable difference are many. The highest part of North America lies between the 40th and 50th degree of north latitude, and the 100th and 110th degree of longitude west from London; for there the greatest rivers originate. The very height, therefore, makes this spot colder than it otherwise would be. It is covered with immense forests, and abounds with large swamps and morasses, which render it incapable of receiving any great degree of heat; so that the rigour of winter is much less tempered by the heat of the earth than in the old continent. To the east lie a number of very

4. North  
America.

\* *M.m. Stock.* 1776.

† Kirwan's *Temperature of Lat.* p. 53.

‡ Ibid.

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large lakes ; and farther north, Hudson's Bay ; about 50 miles on the south of which there is a range of mountains which prevent its receiving any heat from that quarter. This bay is bounded on the east by the mountainous country of Labrador and by a number of islands. Hence the coldness of the north-west winds and the lowness of the temperature. But as the cultivated parts of North America are now much warmer than formerly, there is reason to expect that the climate will become still milder when the country is better cleared of woods, though perhaps it will never equal the temperature of the old continent.

## 5. Islands.

Islands are warmer than continents in the same degree of latitude ; and countries lying to the windward of extensive mountains or forests are warmer than those lying to the leeward. Stones or sand have a less capacity for heat than earth has, which is always somewhat moist ; they heat or cool, therefore, more rapidly and to a greater degree. Hence the violent heat of Arabia and Africa, and the intense cold of Terra del Fuego. Living vegetables alter their temperature very slowly, but their evaporation is great ; and if they be tall and close, as in forests, they exclude the sun's rays from the earth, and shelter the winter snow from the wind and the sun. Woody countries, therefore, are much colder than those which are cultivated.

## SECT. III.

## OF EVAPORATION AND RAIN.

WE found reason formerly to conclude, that the water of the atmosphere exists in the state of *vapour*. We are indebted to the experiments of Saussure and De Luc for much of our knowledge of the qualities of vapour. It is an elastic invisible fluid like common air, but lighter; being to common air, according to Saussure, as 10 to 14, or, according to Kirwan, as 10 to 12: it cannot pass beyond a certain maximum of density, otherwise the particles of water which compose it unite together, and form small, hollow, visible vesicles, called *vesicular vapour*; which is of the same specific gravity with atmospherical air. It is of this vapour that clouds and fogs are composed. This maximum increases with the temperature; and at the heat of boiling water is so great, that steam can resist the whole pressure of the air, and exist in the atmosphere in any quantity.

Nature of  
vapour.

Evaporation, at least in our climate, is about four times greater during the summer than the winter half-year: other things being equal, it is so much the more abundant the greater the difference is between the temperature of the air and of the evaporating surface; so much the less, the nearer they approach to the same temperature; and least of all when they actually arrive at it. Whenever the atmosphere is more than 15

Quantity of  
moisture e-  
vaporated  
annually.



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degrees colder than the evaporating surface, little evaporation takes place at all. Evaporation is powerfully promoted by winds, especially cold winds blowing into warm countries, or warm winds blowing into cold countries\*. Tracts of land covered with trees or vegetables emit more vapour than the same space covered with water. From the experiments of Mr Williams, the quantity appears to be one-third more†: but the method in which these experiments were made (the same objection lies against several of Dr Hailes's experiments, the original discoverer of the fact) prevented him from ascertaining exactly the quantity of vapour emitted by plants. He made the plants grow in a box well closed up from the air, measured the quantity of water with which he supplied them, and at the end of the experiment weighed the box and the plants themselves. By this means he knew pretty accurately the quantity of water which the plants had absorbed, and which had afterwards disappeared; and all this he concluded had been emitted by the plants in the state of vapour. But it is possible that plants have the power of decomposing water, of retaining the hydrogen, and throwing off the oxygen. A part of the water then might be changed into air; and the quantity of this ought to have been ascertained and subtracted. Still, however, the quantity of vapour emitted by vegetables is very great. Evaporation is promoted by heat, and is therefore much greater in the torrid zone than in our latitudes. There, too, the difference between the quantities in summer and winter is much less than in our climate, because the difference

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\* *Temperat. of Lat.* p. 12.

† *Trans. Philad.* ii. 121.

between the temperature of the two seasons is less. Animals also are continually throwing off vapour by insensible perspiration; the quantity of which is exceedingly different, according to the climate, season, and temperament, and cannot therefore be calculated exactly; but it must be very great.

From an experiment made by Dr Watson in England, during summer, when the earth had been burnt up by a month's drought without rain, it appears that 1600 gallons of water were evaporated from a single acre in 12 hours.—If we were to suppose that this represented the mean daily evaporation all over the globe, it would be easy to calculate the quantity of water annually evaporated from the whole of its surface. And if we consider the state of the earth when the experiment was made, the situation of England nearer the pole than the equator, and the evaporation constantly going on from animals and vegetables, which is not taken in, we will surely not think the mean assumed too great. 1600 gallons in 12 hours is 3200 in 24 hours. Let us call it only 3000, which is equal to 693,000 cubic inches. An acre contains 272,640 square inches; so that the daily evaporation from every square inch will be about 0.11 of a cubic inch. This in a year will amount to somewhat more than 40 cubic inches for every square inch. From the experiments of Mr Williams\*, it appears, that in Bradford in New England the evaporation during 1772 amounted to 42.65 inches. But from the way that his experiments were conducted, the amount was probably too great. These experiments, however, serve to show that our calcula-

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\* *Trans. Philad. ii. 135.*

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tion is not perhaps very remote from the truth. Now 40 inches from every square inch on the superficies of the globe make 107,942 cubic miles, equal to the water annually evaporated over the whole globe.

Were this prodigious mass of water all to subsist in the atmosphere at once, it would increase its mass by about a twelfth, and raise the barometer nearly three inches. But this never happens, no day passes without rain in some part of the earth ; so that part of the evaporated water is constantly precipitated again. Indeed it would be impossible for the whole of the evaporated water to subsist in the atmosphere at once, at least in the state of vapour.

The higher regions of the atmosphere contain less vapour than the strata near the surface of the earth. This was observed both by Saussure and De Luc, who mentions several striking proofs of it.

At some height above the tops of mountains the atmosphere is probably still drier ; for it was observed both by Saussure and De Luc, that on the tops of mountains the moisture of the air was rather less during the night than the day. And there can be little doubt that every stratum of air descends a little lower during the night than it was during the day, owing to the cooling and condensing of the stratum nearest the earth. Vapours, however, must ascend very high, for we see clouds forming far above the tops of the highest mountains.

Rain never begins to fall while the air is transparent : the invisible vapours first pass their maximum, and are changed into vesicular vapours ; clouds are formed, and these clouds gradually dissolve in rain. Clouds, however, are not formed in all parts of the ho-

hizon at once; the formation begins in one particular spot, while the rest of the air remains clear as before: this cloud rapidly increases till it overspreads the whole horizon, and then the rain begins.

Formation  
of clouds

It is remarkable, that though the greatest quantity of vapours exist in the lower strata of the atmosphere, clouds never begin to form there, but always at some considerable height. It is remarkable, too, that the part of the atmosphere at which they form has not arrived at the point of extreme moisture, nor near that point even a moment before their formation. They are not formed, then, because a greater quantity of vapour had got into the atmosphere than could remain there without passing its maximum. It is still more remarkable, that when clouds are formed, the temperature of the spot in which they are formed is not always lowered, though this may sometimes be the case. On the contrary, the heat of the clouds themselves is sometimes greater than that of the surrounding air \*. Neither then is the formation of clouds owing to the capacity of air for combining with moisture being lessened by cold: so far from that, we often see clouds, which had remained in the atmosphere during the heat of the day, disappear in the night, after the heat of the air was diminished.

And rain  
cannot be  
accounted  
for.

The formation of clouds and rain, then, cannot be accounted for by a single principle with which we are acquainted. It is neither owing to the saturation of the atmosphere, nor the diminution of heat, nor the mixture of airs of different temperatures, as Dr Hutton supposes; for clouds are often formed without any

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\* De Luc sur la *Meteorol.* ii, 100.



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wind at all either above or below them; and even if this mixture constantly took place, the precipitation, instead of accounting for rain, would be almost imperceptible.

It is a very remarkable fact, that evaporation often goes on for a month together in hot weather without any rain. This sometimes happens in this country; it happens every year in the torrid zone. Thus at Calcutta, during January 1785, it never rained at all\*: the mean of the thermometer for the whole month was  $66\frac{1}{2}$  degrees; there was no high wind, and indeed during great part of the month little wind at all.

The quantity of water evaporated during such a drought must be very great; yet the moisture of the air, instead of being increased, is constantly diminishing, and at last disappears almost entirely. For the dew, which is at first copious, diminishes every night; and if Dr Watson's experiment formerly mentioned be attended to, it will not be objected that the quantity of evaporation is also very much diminished. Of the very dry state to which the atmosphere is reduced during long droughts, the violent thunder-storms with which they often conclude is a proof, and a very decisive one. Now what becomes of all this moisture? It is not accumulated in the atmosphere above the country from which it was evaporated, otherwise the whole atmosphere would in a much less period than a month be perfectly saturated with moisture. If it be carried up daily through the different strata of the atmosphere, and wafted to other regions by superior currents of air, how is it possible to account for the different electrical

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\* *Asiatic Researches*, ii. Appendix.



state of the clouds situated between different strata, which often produces the most violent thunder storms? Are not vapours conductors of the electric fluid; and would they not have daily restored the equilibrium of the whole atmosphere through which they passed? Had they traversed the atmosphere in this manner, there would have been no negative and positive clouds, and consequently no thunder-storms. They could not have remained in the lower strata of the atmosphere, and been daily carried off by winds to other countries; for there are often no winds at all during several days to perform this office; nor in that case would the dews diminish, nor could their presence fail to be indicated by the hygrometer.

It is impossible for us to account for this remarkable fact upon any principle with which we are acquainted. The water can neither remain in the atmosphere, nor pass through it in the state of vapour. It must therefore assume some other form; but what that form is, or how it assumes it, we know not.

There are then two steps of the process between evaporation and rain, of which at present we are completely ignorant: 1. What becomes of the vapour after it enters into the atmosphere. 2. What makes it lay aside the new form which it must have assumed, and return again to its state of vapour, and fall down in rain. And till these two steps be discovered by experiments and observations, it will be impossible for us to give a rational or a useful theory of rain.

Dr Pratt of Exeter has endeavoured to prove, in a very ingenious treatise, that water is decomposed during its evaporation, and converted into oxygen and hydrogen gas: but the absence of any perceptible quan-

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tity of this last gas in the atmosphere, even when rain is actually forming, cannot be accounted for unless we suppose that the products of the decomposition are different. Girtanner's theory, that azot is composed of hydrogen and oxygen, would remove every difficulty; but unfortunately that theory is not only destitute of proof, but militates against the known properties of water, azot, and hydrogen. We must therefore be cautious in drawing any conclusion till future discoveries have removed the obscurity in which the phenomena of rain are at present involved.

Quantity  
of rain.

The mean annual quantity of rain is greatest at the equator, and decreases gradually as we approach the poles. Thus at

\*Granada, Antilles,  $12^{\circ}$  N. lat. it is 126 inches

\*Cape François, St

Domingo . . . .  $19^{\circ} 46'$  . . . . 120

†Calcutta . . . . . 22 23 . . . . 81

\*Rome . . . . .  $41^{\circ} 54'$  . . . . 39

‡England . . . . .  $33^{\circ}$  . . . . 32

§Petersburgh . . . .  $59^{\circ} 16'$  . . . . 16

On the contrary, the number of rainy days is smallest at the equator, and increases in proportion to the distance from it. From north latitude  $12^{\circ}$  to  $43^{\circ}$  the mean number of rainy days is 78; from  $43^{\circ}$  to  $46^{\circ}$  the mean number is 103; from  $46^{\circ}$  to  $50^{\circ}$  it is 134; from  $51^{\circ}$  to  $60^{\circ}$ , 161 ¶.

\* The number of rainy days is often greater in winter

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\* Cotte, *Jour. de Phys.* Oct. 1791, p. 264.

† *Asiatic Researches*, i. and ii. Appendix.

‡ *Phil. Trans.* § *Edin. Trans.* ii. 244.

¶ P. Cotte, *ibid.*

than in summer ; but the quantity of rain is greater in summer than in winter \*. At Petersburg, the number of rainy or snowy days during winter is 84, and the quantity which falls is only about five inches ; during summer the number of rainy days is nearly the same, but the quantity which falls is about 11 inches †.

More rain falls in mountainous countries than in plains. Among the Andes it is said to rain almost perpetually, while in Egypt it hardly ever rains at all. If a rain-gauge be placed on the ground, and another at some height perpendicularly above it, more rain will be collected into the lower than into the higher ; a proof that the quantity of rain increases as it descends, owing perhaps to the drops attracting vapour during their passage through the lower strata of the atmosphere where the greatest quantity resides. This, however, is not always the case, as Mr Copland of Dumfries discovered in the course of his experiments ‡. He observed also, that when the quantity of rain collected in the lower gauge was greatest, the rain commonly continued for some time ; and that the greatest quantity was collected in the higher gauge only either at the end of great rains, or during rains which did not last long. These observations are important, and may, if followed out, give us new knowledge of the causes of rain. They seem to show, that during rain the atmosphere is somehow or other brought into a state which induces it to part with its moisture ; and that the rain continues as long as this state continues. Were a sufficient number of observations made on this subject in different

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\* P. Cotte, *Jour. de Phys.* Oct. 1791, 264.

† *Edin. Trans.* ii. 244.

‡ *Manchest. Trans.* iv. 619.

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places, and were the atmosphere carefully analysed during dry weather, during rain, and immediately after rain, we might soon perhaps discover the true theory of rain.

Rain falls in all seasons of the year, at all times of the day, and during the night as well as the day; tho', according to M. Toaldo, a greater quantity falls during the day than the night. The cause of rain, then, whatever it may be, must be something which operates at all times and seasons. Rain falls also during the continuance of every wind, but oftenest when the wind blows from the south. Falls of rain often happen likewise during perfect calms.

It appears from a paper published by M. Cotte in the *Journal de Physique* for October 1791, containing the mean quantity of rain falling at 147 places, situated between north lat.  $11^{\circ}$  and  $60^{\circ}$ , deduced from tables kept at these places, that the mean annual quantity of rain falling in all these places is 34.7 inches. Let us suppose then (which cannot be very far from the truth) that the mean annual quantity of rain for the whole globe is 34 inches. The superficies of the globe consists of 170,981,012 square miles, or 686,401,498,471,475,200 square inches. The quantity of rain therefore falling annually will amount to 23,337,650,812,030,156,800 cubic inches, or somewhat more than 91,751 cubic miles of water. This is 16,191 cubic miles of water less than the quantity of water evaporated. It seems probable, therefore, if the imperfection of our data warrant any conclusion, that some of the vapour is actually decomposed in the atmosphere, and converted into oxygen and hydrogen gas.

The dry land amounts to 52,745,253 square miles;

the quantity of rain falling on it annually therefore will amount to 30,960 cubic miles. The quantity of water running annually into the sea is 13,140 cubic miles; a quantity of water equal to which must be supplied by evaporation from the sea, otherwise the land would soon be completely drained of its moisture.

The quantity of rain falling annually in Great Britain may be seen from the following TABLE:

Rain in  
Britain.

Years of observation.	Places.	Rain in inches.
3	Dover * . . . . .	37.52
5	Ware, Hertfordshire * . . . . .	23.6
8	London † . . . . .	17.5
8	Kimbolton ‡ . . . . .	23.9
45	Lyndon § . . . . .	22.210
5	Chatsworth, Derbyshire * . . . . .	27.865
8	Manchester * . . . . .	43.1
18	Liverpool * . . . . .	34.41
7	Lancaster * . . . . .	40.3
5	Kendal * . . . . .	61.223
14	Dumfries * . . . . .	36.127
10	Braxholm, 44 miles south-west of Berwick    . . . . .	31.26
5	Langholm    . . . . .	36.73
5	Dalkeith    . . . . .	25.124
20	Glasgow ¶ . . . . .	31.
8	Hawkhill ** . . . . .	28.966
	Mean	32.532

\* *Manchest. Trans.* iv.

† *Phil. Trans.* Tables of Observations.

‡ *Ibid.* vol. lxxix. part i.

§ Mr Barker, *Ibid.*

|| *Edin. Trans.* i. 208.

¶ *Statist. Account of Scotland*, v. 245.

\*\* *Edin. Trans.* i. 333.



Book I.

In this country it generally rains less in March than in November, in the proportion at a medium of 7 to 12. It generally rains less in April than October in the proportion of 1 to 2 nearly at a medium. It generally rains less in May than September, the chances that it does so are at least as 4 to 3; but when it rains plentifully in May (as 1.8 inches or more), it generally rains but little in September; and when it rains one inch or less in May, it rains plentifully in September\*.

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## SECT. IV.

## OF WIND.

No phenomenon in meteorology has more engaged the attention of men of observation than the *winds*, or those currents which so often disturb the tranquillity of the atmosphere. The subject is not only curious, but highly interesting; for upon their direction and force navigation in a great measure depends; the temperature of climates is greatly influenced by them; and they are absolutely necessary to preserve the salubrity of the atmosphere. To be acquainted with the laws by which they are regulated, and to be able to calculate beforehand the consequences of these laws, has been in every age the eager wish of philosophers. But whether it has been owing to an improper method of studying this subject, or to its lying beyond the reach of the human fa-

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\* Kirwan, *Irish Trans.* v. 21.

culties, philosophers have not made that progress in it which the sanguine imaginations of some individuals led them to expect. Many discoveries indeed have been made; and from the numbers and the genius of the philosophers at present engaged in this study, others equally important may be expected. But, notwithstanding this, many of the phenomena remain unexplained, and a rational and satisfactory theory seems still beyond our reach. I shall in this Section give as complete a detail as possible of the natural history of the winds in the different parts of the world, and then consider how they may be explained.

As the winds are much more regular between the tropics than in the temperate zones, it will be proper in the first place to begin with them.

In those parts of the Atlantic and Pacific Oceans which lie nearest the equator, there is a regular wind during the whole year called the *trade-wind*. On the north side of the equator it blows from the north-east, varying frequently a point or two towards the north or east; and on the south side of it, from the south east; changing sometimes in the same manner towards the south or east. The space included between the second and fifth degree of north latitude is the internal limit of these two winds. There the winds can neither be said to blow from the north nor the south; calms are frequent, and violent storms. This space varies a little in latitude as the sun approaches either of the tropics.—In the Atlantic Ocean the trade-winds extend farther north on the American than on the African coast; and as we advance westward, they become gradually more easterly, and decrease in strength \*. Their force di-

1. Winds in the torrid zone.

Trade-wind.

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\* Dr Halley, *Phil. Trans. Abr.* vol. ii. p. 134.

## Book I.

minishes likewise as we approach their utmost boundaries. It has been remarked also, that as the sun approaches the tropic of Cancer, the south-east winds become gradually more southerly, and the north-east winds more easterly: exactly the contrary takes place when the sun is approaching the tropic of Capricorn\*.

## Monsoons.

The trade-wind blows constantly in the Indian Ocean from the 10th degree of south latitude to near the 30th: But to the northward of this the winds change every six months, and blow directly opposite to their former course. These regular winds are called *monsoons*, from the Malay word *moassin*, which signifies “a season †.” When they shift their direction, variable winds and violent storms succeed, which last for a month and frequently longer; and during that time it is dangerous for vessels to continue at sea.

The monsoons in the Indian Ocean may be reduced to two; one on the north and another on the south side of the equator; which extend from Africa to the longitude of New Holland and the east coast of China, and which suffer partial changes in particular places from the situation and inflection of the neighbouring countries.

1. Between the 3d and 10th degrees of south latitude the south-east trade-wind continues from April to October; but during the rest of the year the wind blows from the north-west ‡. Between Sumatra and New Holland this monsoon blows from the south during our summer months, approaching gradually to the south-

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\* Dr Halley, *Phil. Trans.* Abr. vol. ii. p. 134.

† Forest's *Voyage*, p. 95.

‡ Dr Halley, *Phil. Trans.* Abr. vol. ii. 136.

east as we advance towards the coast of New Holland; it changes about the end of September, and continues in the opposite direction till April\*. Between Africa and Madagascar its direction is influenced by the coast; for it blows from the north-east from October to April, and during the rest of the year from the south-west †.

2. Over all the Indian Ocean, to the northward of the 3d degree of south latitude, the north-east trade-wind blows from October to April, and a south-west wind from April to October ‡. From Borneo, along the coast of Malacca and as far as China, this monsoon in summer blows nearly from the south, and in winter from the north by east §. Near the coast of Africa, between Mozambique and Cape Guardafui, the winds are irregular during the whole year, owing to the different monsoons which surround that particular place. Monsoons are likewise regular in the Red Sea; between April and October they blow from the north-west, and during the other months from the south-east, keeping constantly parallel to the coast of Arabia ||.

Monsoons are not altogether confined to the Indian Ocean; on the coast of Brazil, between Cape St Augustine and the island of St Catherine, the wind blows between September and April from the east or north-east, and between April and September from the south-west ¶. The bay of Panama is the only place on the west side of a great continent where the wind shifts

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\* Dr Halley, *Phil. Trans. Abr.* vol. ii. p. 136.

† Bruce's *Travels*, vol. i. p. 459.

‡ Dr Halley, *Phil. Trans. Abr.* vol. ii. p. 136.

§ Dr Halley, *ibid.*

|| Bruce's *Travels*, vol. i. ch. 4.

¶ Sir Walter Raleigh's *Voyage*, Forest's *Voyage*, p. 97.



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regularly at different seasons: there it is easterly between September and March; but between March and September it blows chiefly from the south and south-west.

Such in general is the direction of the winds in the torrid zone all over the Atlantic, Pacific, and Indian Oceans; but they are subject to particular exceptions, which it is proper to enumerate.—On the coast of Africa, from Cape Bayador to Cape Verde, the winds are generally north-west; from hence to the island of St Thomas near the equator they blow almost perpendicular to the shore, bending gradually, as we advance southwards, first to the west and then to the south-west\*. On the coast of New Spain likewise, from California to the Bay of Panama, the winds blow almost constantly from the west or south-west, except during May, June, and July, when land-winds prevail, called by the Spaniards *Popogayos*. On the coast of Chili and Peru†, from 20° or 30° south latitude, to the equator, and on the parallel coast of Africa, the wind blows during the whole year from the south, varying according to the direction of the land towards which it inclines, and extending much farther out to sea on the American than the African coast. The trade winds are also interrupted sometimes by westerly winds in the Bay of Campeachy and the Bay of Honduras.

As to the countries between the tropics, we are too little acquainted with them to be able to give a satisfactory history of their winds.

Sea and  
land bree-  
zes.

In all maritime countries between the tropics of any extent, the wind blows during a certain number of hours

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\* Dr Halley, *Phil. Trans. Abr.* vol. ii. p. 136.

† Sir Walter Raleigh's *Voyage*.—Dr Garden, *Phil. Trans. Abr.* vol. ii. p. 132.



every day *from* the sea, and during a certain number *towards* the sea from the land; these winds are called the *sea* and *land breezes*. The sea-breeze generally sets in about ten in the forenoon, and blows till six in the evening; at seven the land breeze begins, and continues till eight in the morning, when it dies away\*. During summer the sea-breeze is very perceptible on all the coasts of the Mediterranean Sea†, and even sometimes as far north as Norway‡.

In the island of St Lewis on the coast of Africa, in 16° north latitude, and 16° west longitude, the wind during the rainy season, which lasts from the middle of July to the middle of October, is generally between the south and east; during the rest of the year it is for the most part east or north-east in the morning; but as the sun rises, the wind approaches gradually to the north, till about noon it gets to the west of north, and is called a *sea-breeze*. Sometimes it shifts to the east as the sun descends, and continues there during the whole night. In February, March, April, May, and June, it blows almost constantly between the north and west§. In the island of Balama, which lies likewise on the west coast of Africa, in the 11th degree of north latitude, the wind during nine months of the year blows from the south-west; but in November and December a very cold wind blows from the north-east||.

Winds in  
St Lewis,

Balama,

In the kingdom of Bornou, which lies between the 16th and 20th degree of north latitude, the warm season is introduced about the middle of April by sultry

Bornou,

\* Marsden's *Hist. of Sumatra*, p. 17.—Buffon's *Nat. Hist.* vol. i. p. 385.

† Volney's *Travels*.

‡ Pontoppidon's *Nat. Hist. of Norway*.

§ Dr Schotte, *Phil Trans.* vol. lxx. art. 25.

|| P. Beaver, Esq. See Map in Wadstrom's *Essay on Colonization*.

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Fezzan,

winds from the south-east, which bring along with them a deluge of rain \*. In Fezzan, which is situated about the 25th degree of north latitude and the 35th degree of east longitude, the wind from May to August blows from the east, south-east, or south-west, and is intensely hot †.

Abyssinia,

In Abyssinia the winds generally blow from the west, north-west, north, and north-east. During the months of June, July, August, September, and October, the north and north-east winds blow almost constantly, especially in the morning and evening; and during the rest of the year they are much more frequent than any other winds ‡.

East and  
West In-  
dies.

At Calcutta, in the province of Bengal, the wind blows during January and February from the south-west and south; in March, April, and May, from the south; in June, July, August, and September, from the south and south-east; in October, November, and December, from the north-west §. At Madras the most frequent winds are the north and north-east. At Tivoli in St Domingo, and at Iles de Vaches, the wind blows oftenest from the south and south-east ||.—From these facts it appears, that in most tropical countries with which we are acquainted, the wind generally blows *from* the nearest ocean, except during the coldest months, when it blows *towards* it.

2. In the  
temperate  
zones.

In the temperate zones the direction of the winds is by no means so regular as between the tropics. Even

\* *African Association*, p. 200.† *Ibid.*‡ *Bruce's Travels*, vol. iv. p. 651.§ *Asiatic Researches*, vols. i. and ii. Append.|| P. Cotte, *Jour. de Phys.* 1791.

in the same degree of latitude we find them often blowing in different directions at the same time ; while their changes are frequently so sudden and so capricious, that to account for them has hitherto been found impossible. When winds are violent, and continue long, they generally extend over a large tract of country ; and this is more certainly the case when they blow from the north or east than from any other points \*. By the multiplication and comparison of Meteorological Tables, some regular connection between the changes of the atmosphere in different places may in time be observed, which will at last lead to a satisfactory theory of the winds. It is from such tables chiefly that the following facts have been collected.

In Virginia, the prevailing winds are between the south-west, west, north, and north-west ; the most frequent is the south-west, which blows more constantly in June, July, and August, than at any other season. The north-west winds blow most constantly in November, December, January, and February †.—At Ipswich in New England the prevailing winds are also between the south-west, west, north, and north-east ; the most frequent is the north-west ‡ : But at Cambridge, in the same province, the most frequent wind is the south-east §. The predominant winds at New York are the north and west || : And in Nova Scotia north-west winds blow for three-fourths of the year ¶ —The same wind blows most frequently at Montreal in Ca-

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\* Derham's *Physico-Theology*, ch. ii.

† Jefferson's *Virginia*, p. 123.—*Trans. Philad.* ii. art. 10.

‡ *Trans. Amer. Acad.* i. 336.

§ M. Cotte, *Jour. de Phys.* 1791.

|| *Ibid.*

¶ *Present State of Nova Scotia and Canada*, p. 38.

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nada; but at Quebec the wind generally follows the direction of the river St Lawrence, blowing either from the north-east or south-west\*.—At Hudson's Bay westerly winds blow for three-fourths of the year; the north-west wind occasions the greatest cold, but the north and north-east are the vehicles of snow†.

It appears from these facts, that westerly winds are most frequent over the whole eastern coast of North America; that in the southern provinces south-west winds predominate; and that the north-west become gradually more frequent as we approach the frigid zone.

In Egypt, In Egypt, during part of May, and during June, July, August, and September, the wind blows almost constantly from the north, varying sometimes in June to the west, and in July to the west and the east; during part of September, and in October and November, the winds are variable, but blow more regularly from the east than any other quarter; in December, January, and February, they blow from the north, north-west, and west; towards the end of February they change to the south, in which quarter they continue till near the end of March; during the last days of March and in April they blow from the south-east, south, and south-west, and at last from the east; and in this direction they continue during a part of May‡.

In the Mediterranean

In the Mediterranean the wind blows nearly three-fourths of the year from the north; about the equinoxes there is always an easterly wind in that sea, which is generally more constant in spring than in au-

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\* Cotte, *Jour. de Phys.* 1791.

† Pennant's *Suppl. to Arctic Zool.* p. 41.

‡ Volney's *Travels*, i. 58.



tumn\*. These observations do not apply to the gut of Gibraltar, where there are seldom any winds except the east and the west.—At Bastia, in the island of Corsica, the prevailing wind is the south-west†.

In Syria the north wind blows from the autumnal Asia, equinox to November; during December, January, and February, the winds blow from the west and south-west; in March they blow from the south, in May from the east, and in June from the north. From this month to the autumnal equinox the wind changes gradually as the sun approaches the equator; first to the east, then to the south, and lastly to the west‡.—At Bagdad the most frequent winds are the south-west and north-west; at Pekin, the north and the south§; at Kamtschatka, on the north-east coast of Asia, the prevailing winds blow from the west||.

In Italy the prevailing winds differ considerably according to the situation of the places where the observations have been made: At Rome and Padua they are northerly, at Milan easterly¶.—All that we have been able to learn concerning Spain and Portugal is, that on the west coast of these countries the west is by far the most common wind, particularly in summer; and that at Madrid the wind is north-east for the greatest part of the summer, blowing almost constantly from the Pyrenean mountains\*\*.—At Berne in Switzerland the prevailing winds are the north and west; at St Gottard,

South of  
Europe,

\* Volney's *Trav.* i. 59. and 65.

† Cotte, *Jour. de Phys.* 1791.

‡ Volney's *Trav.* i. 326.

§ Cotte, *Ibid.*

|| Pennant's *Arctic Zool.* p. cxiii.

¶ Cotte, *Ibid.*

\*\* Bohun's *Hist. of Winds*, p. 116.



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the north-east ; at Lausanne, the north-west and south-west\*.

France,

Father Cotte has given us the result of observations made at 86 different places of France\* ; from which it appears, that along the whole south coast of that kingdom the wind blows most frequently from the north, north-west, and north-east ; on the west coast, from the west, south-west, and north-west ; and on the north coast, from the south-west. That in the interior parts of France the south-west wind blows most frequently in 18 places ; the west wind in 14 ; the north in 13 ; the south in 6 ; the north-east in 4 ; the south-east in 2 ; the east and north-west each of them in one. —On the west coast of the Netherlands, as far north as Rotterdam, the prevailing winds are probably the south-west, at least this is the case at Dunkirk and Rotterdam\*. It is probable also that along the rest of this coast, from the Hague to Hamburg, the prevailing winds are the north-west, at least these winds are most frequent at the Hague and at Franeker\*. —The prevailing wind at Delft is the south-east ; and at Breda the north and the east\*.

Germany,

In Germany the east wind is most frequent at Gottingen, Munich, Weisseburg, Dusseldorf, Saganum, Erford, and at Buda in Hungary ; the south-east at Prague and Wirtzburg ; the north-east at Ratisbon ; and the west at Manheim and Berlin\*.

Britain,

From an average of ten years of the register kept by order of the Royal Society, it appears that at London the winds blow in the following order :

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\* Cotte, *Jour. de Phys.* 1791.

WINDS.	DAYS.	WINDS.	DAYS.
South-west . . . . .	112	South-east . . . . .	32
North-east . . . . .	58	East . . . . .	26
North-west . . . . .	50	South . . . . .	18
West . . . . .	53	North . . . . .	16

It appears, from the same register, that the south-west wind blows at an average more frequently than any other wind during every month of the year, and that it blows longest in July and August; that the north-east blows most constantly during January, March, April, May, and June, and most seldom during February, July, September, and December; and that the north-west wind blows oftener from November to March, and more seldom during September and October than any other months. The south-west winds are also most frequent at Bristol, and next to them are the north-east\*.

The following TABLE of the winds at Lancaster has been drawn up from a register kept for seven years at that place†.

WINDS.	DAYS.	WINDS.	DAYS.
South-west . . . . .	92	South-east . . . . .	35
North-east . . . . .	67	North . . . . .	30
South . . . . .	51	North-west . . . . .	26
West . . . . .	41	East . . . . .	17

The following TABLE is an abstract of nine years observations made at Dumfries by Mr Copland‡.

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\* *Pbil. Trans.* lxxi. 2.

† *Manch. Trans.* iv. 234.

‡ *Ibid.*

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		South . . . . .	82½	North . . . . .	36½
		West . . . . .	69	North-west . . . . .	25½
		East . . . . .	68	South-east . . . . .	18½
		South-west . . . . .	50½	North-east . . . . .	14½

The following TABLE is an abstract of seven years observations made by Dr Meek at Cambuslang near Glasgow\*:

WINDS.	DAYS.	WINDS.	DAYS.
South-west . . . . .	174	North-east . . . . .	104
North-west . . . . .	140	South-east . . . . .	147

It appears, from the register from which this table was extracted, that the north-east wind blows much more frequently in April, May, and June, and the south-west in July, August, and September, than at any other period. The south-west is by far the most frequent wind all over Scotland, especially on the west coast. At Saltcoats in Airshire, for instance, it blows three-fourths of the year; and along the whole coast of Murray, on the north-east side of Scotland; it blows for two-thirds of the year. East winds are common over all Great Britain during April and May; but their influence is felt most severely on the eastern coast.

The following TABLE exhibits a view of the number of days during which the westerly and easterly winds blow in a year at different parts of the island. Under the term *westerly* are included the north-west, west, south-west, and south; the term *easterly* is taken in the same latitude.

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\* *Statistical Account of Scotland*, v. 245.

Years of Observ.	Places.	WIND.	
		Westerly.	Easterly.
10	London - - -	233	132
7	Lancaster - - -	216	149
51	Liverpool * - - -	170	175
9	Dumfries - - -	227.5	137.5
10	Brånxholm, 54 miles south- west of Berwick †	232	133
7	Cambuslang - - -	214	151
8	Hawkhill, near Edinburgh †	229.5	135.5
Mean		217.4	144.7

In Ireland the south-west and west are the grand Ireland, trade-winds, blowing most in summer, autumn, and winter, and least in spring. The north-east blows most in spring, and nearly double to what it does in autumn and winter. The south-east and north-west are nearly equal, and are most frequent after the south-west and west§.

At Copenhagen the prevailing winds are the east North of and south-east; at Stockholm, the west and north ¶. Europe.  
In Russia, from an average of a register of 16 years, the winds blow from November to April in the following order:

	W.	N.W.	E.	S.W.	S.	N.E.	N.	S.E.
Days	45	26	23	22	20	19	14	12

And during the other six months,

	W.	N.W.	E.	S.W.	S.	N.E.	N.	S.E.
Days	27	27	19	24	22	15	32	18

\* Manchester Trans. iv.

† Edin. Trans. i. 203.

‡ Ibid.

§ Rutt's Hist. of the Weather, &c. in Dublin.

¶ Cotte, Jour. de Phys. 1791.

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The west wind blows during the whole year 72 days; the north-west 53; the south-west and north 46 days each. During summer it is calm for 41 days, and during winter for 21 \*. In Norway the most frequent winds are the south, the south-west, and south-east. The wind at Bergen is seldom directly west, but generally south-west or south-east; a north-west, and especially a north-east wind, are but little known there†.

From the whole of these facts, it appears that the most frequent winds on the south coasts of Europe are the north, the north-east, and north-west; and on the western coast, the south-west: that in the interior parts which lie most contiguous to the Atlantic Ocean, south-west winds are also most frequent; but that easterly winds prevail in Germany. Westerly winds are also most frequent on the north-east coast of Asia.

3. South  
temperate  
zone.

It is probable that the winds are more constant in the south temperate zone, which is in a great measure covered with water, than in the north temperate zone, where their direction must be frequently interrupted and altered by mountains and other causes.

M. de la Baille, who was sent thither by the French king to make astronomical observations, informs us, that at the Cape of Good Hope the main winds are the south-east and north-west; that other winds seldom last longer than a few hours; and that the east and north-east winds blow very seldom. The south-east wind blows in most months of the year, but chiefly from October to April; the north-west prevails during the other six months, bringing along with it rain, and

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\* Guthrie on the Climate of Russia, *Edin. Trans.* ii.

† Pontoppidan's *Nat. Hist. of Norway*, part i.



tempests, and hurricanes. Between the Cape of Good Hope and New Holland the winds are commonly westerly, and blow in the following order: north-west, south-west, west, north\*.

In the great South Sea, from latitude  $30^{\circ}$  to  $40^{\circ}$  south, the south-east trade-wind blows most frequently, especially when the sun approaches the tropic of Capricorn; the wind next to it in frequency is the north-west, and next to that is the south-west. From south latitude  $40^{\circ}$  to  $50^{\circ}$  the prevailing wind is the north-west, and next the south-west. From  $50^{\circ}$  to  $60^{\circ}$ , the most frequent wind is also the north-west, and next to it is the west†.

Thus it appears that the trade-winds sometimes extend farther into the south temperate zone than their usual limits, particularly during summer; that beyond their influence the winds are commonly westerly, and that they blow in the following order: north-west, south-west, west.

Such is the present state of the history of the direction of the winds. In the torrid zone they blow constantly from the north-east on the north side of the equator, and from the south-east on the south side of it. In the north temperate zone they blow most frequently from the south-west; in the south temperate zone from the north-west, changing, however, frequently to all points of the compass; and in the north temperate zone blowing particularly during spring from the north-east.

As to the velocity of the wind, its variations are almost infinite; from the gentlest breeze to the hurri-

Velocity of  
the winds.

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\* Meteorological Tables at the end of Philip's and White's *Voyages*.

† Wales's *Meteor. Tables*.

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cane which tears up trees and blows down houses. It has been remarked, that our most violent winds take place when neither the heat nor the cold is greatest; that violent winds generally extend over a great tract of country; and that they are accompanied with sudden and great falls in the mercury of the barometer. The wind is sometimes very violent at a distance from the earth, while it is quite calm at its surface. On one occasion Lunardi went at the rate of 70 miles an hour in his balloon, though it was quite calm at Edinburgh when he ascended, and continued so during his whole voyage. Let us now consider the cause of these numerous currents in the atmosphere.

Explan-  
ation of the  
cause of the  
trade-  
winds.

It cannot be doubted that the surface of the earth under the torrid zone is much more heated by the rays of the sun than under the frozen or temperate zones, because the rays fall upon it much more perpendicularly. This heat is communicated to the air near the surface of the torrid zone, which being thereby rarefied, ascends; and its place is supplied by colder air, which rushes in from the north and south.

Now the diurnal motion of the earth is greatest at the equator, and diminishes gradually as we approach the poles, where it ceases altogether. Every spot of the earth's surface at the equator moves at the rate of 15 geographical miles in a minute; at the  $40^{\circ}$  of latitude, it moves at about  $11\frac{1}{2}$  miles in a minute; and at the  $30^{\circ}$ , at nearly 13 miles. The atmosphere, by moving continually round along with the earth, has acquired the same degree of motion; so that those parts of it which are above the equator move faster than those which are at a distance. Were a portion of the atmosphere to be transported in an instant from latitude  $30^{\circ}$

to the equator, it would not immediately acquire the velocity of the equator; the eminences of the earth therefore would strike against it, and it would assume the appearance of an east wind. This is the case in a smaller degree with the air that flows towards the equator, to supply the place of the rarefied air, which is continually ascending; and this, when combined with its real motion from the north and south, must cause it to assume the appearance of a north-easterly wind on this side the equator, and of a south-easterly beyond it.

The motion westwards occasioned by this difference in celerity alone would not be great; but it is farther increased by another circumstance. Since the rarefaction of the air in the torrid zone is owing to the heat derived from the contiguous earth, and since this heat is owing to the perpendicular rays of the sun, those parts must be hottest where the sun is actually vertical, and consequently the air over them must be most rarefied; the contiguous parts of the atmosphere will therefore be drawn most forcibly to that particular spot. Now since the diurnal motion of the sun is from east to west, this hottest spot will be continually shifting westwards, and this will occasion a current of the atmosphere in that direction. That this cause really operates, appears from a circumstance already mentioned: when the sun approaches either of the tropics, the trade-wind on the same side of the equator assumes a more easterly direction, evidently from the cause here mentioned; while the opposite trade-wind, being deprived of this additional impulse, blows in a direction more perpendicular to the equator.

The westerly direction of the trade-winds is still farther increased by another cause. Since the attraction

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of the sun and moon produces so remarkable an effect upon the ocean, we cannot but suppose that an effect equally great at least is produced upon the atmosphere. Indeed as the atmosphere is nearer the moon than the sea is, the effect produced by attraction upon it ought to be greater. When we add to this the elasticity of the air, or that disposition which it has to dilate itself when freed from any of its pressure, we cannot but conclude that the tides in the atmosphere are considerable. Now since the apparent diurnal motion of the moon is from east to west, the tides must follow it in the same manner, and consequently produce a constant motion in the atmosphere from east to west.

All these different causes probably combine in the production of the trade-winds; and from their being sometimes united, and sometimes distinct or opposite, arise all those little irregularities which take place in the direction and force of the trade-winds.

Why their  
limit is  
in the  
northern  
hemisphere.

Since the great cause of these winds is the rarefaction of the atmosphere by the heat of the sun, its ascension, and the consequent rushing in of colder air from the north and south, the internal boundary of the trade-winds must be that parallel of the torrid zone which is hottest, because there the ascension of the rarefied air must take place. Now since the sun does not remain stationary, but is constantly shifting from one tropic to the other, we ought naturally to expect that this boundary would vary together with its exciting cause; that therefore when the sun is perpendicular to the tropic of Cancer, the north-east trade-winds would extend no farther south than north latitude  $23.5^{\circ}$ ; that the south-east wind would extend as far north; and that when the sun was in the tropic of Capricorn, the very con-



rary would take place. We have seen, however, that though this boundary be subject to considerable changes from this very cause, it may in general be considered as fixed between the second and fifth degrees of north latitude.

Though the sun be perpendicular to each of the tropics during part of the year, he is for one half of it at a considerable distance; so that the heat which they acquire while he is present is more than lost during his absence. But the sun is perpendicular to the equator twice in a year, and never farther distant from it than  $23\frac{1}{2}^{\circ}$ : being therefore twice every year as much heated, and never so much cooled as the tropics, its mean heat must be greater, and the atmosphere in consequence generally most rarefied at that place. Why then, it will be asked, is not the equator the boundary of the two trade-winds? To speak more accurately than we have hitherto done, the internal limit of these winds must be that parallel where the mean heat of the earth is greatest. This would be the equator, were it not for a reason which shall now be explained.

It has been shewn by astronomers, that the orbit of the earth is an ellipsis, and that the sun is placed in one of the foci. Were this orbit to be divided into two parts by a straight line perpendicular to the transverse axis, and passing through the centre of the sun, one of these parts would be less than the other; and the earth, during its passage through this smaller part of its orbit, would constantly be nearer the sun than while it moved through the other portion. The celerity of the earth's motion in any part of its orbit is always proportioned to its distance from the sun; the nearer it is to the sun, it moves the faster; the farther distant, the slower. The earth passes over the smaller portion



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of its orbit during our winter; which must therefore be shorter than our summer, both on account of this part of the orbit being smaller than the other, and on account of the increased celerity of the earth's motion. The difference, according to Cassini, is 7 days, 23 hours, and 53 minutes. While it is winter in the northern it is summer in the southern hemisphere; wherefore the summer in the southern hemisphere must be just as much shorter than the winter as our winter is shorter than our summer. The difference therefore between the length of the summer in the two hemispheres is almost 16 days. The summer in the northern hemisphere consists of  $190\frac{1}{2}$  days, while in the southern it consists only of  $174\frac{1}{2}$ . They are to one another nearly in the proportion of 14 to 12.8; and the heat of the two hemispheres may probably have nearly the same proportion to one another. The internal limit of the trade-winds ought to be that parallel where the mean heat of the globe is greatest: this would be the equator, if both hemispheres were equally hot; but since the northern hemisphere is the hottest, that parallel ought to be situated somewhere in it; and since the difference between the heat of two hemispheres is not great, the parallel ought not to be far distant from the equator\*.

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\* This parallel could be determined by calculation, provided the mean heat of both the segments into which it divides the globe were known. Let the radius of this globe be = 1, the circumference of a great circle = 6, and consequently the arc of a great circle = 3, and the solid contents of a hemisphere = 2. Since the internal limit of the trade-winds is not far distant from the equator, we may consider that portion of the sphere intercepted between it and the equator as a cylinder, the base of which is the equator, and its height the arc intercepted between the equator and the internal limit of the trade-winds. Let this arc be  $x$ , and consequently

The trade-wind would blow regularly round the whole globe if the torrid zone were all covered with water. If the Indian Ocean were not bounded by land on the north, it would blow there in the same manner as it does in the Atlantic and Pacific Oceans. The rays of light pass through a transparent body without communicating any, or at least but a small degree of heat. If a piece of wood be inclosed in a glass vessel, and the focus of a burning glass directed upon it, the wood will be burnt to ashes, while the glass through which all the rays passed is not even heated. When an opaque body is exposed to the sun's rays, it is heated in proportion to its opacity. If the bulb of a thermometer be exposed to the sun, the quicksilver will not rise so high as it would do if this bulb were painted black. Land is much more opaque than water; it becomes therefore much warmer when both are equally exposed to the influence

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the cylinder itself  $= 3x$ , equal to the excess of the southern segment into which this internal limit divides the globe above the northern. Let the heat of the northern segment be  $= n$ , and that of the southern  $= s$ . The southern segment is  $= 2 + 3x$ , the northern  $= 2 - 3x$ . Now let us suppose that the bulk of each segment is reciprocally as its heat, and we shall have this formula,  $2 + 3x : 2 - 3x :: n : s$ . Wherefore

$$x = \frac{2n - 2s}{3n + 3s}. \text{ Now if we suppose } n = 14, \text{ and } s = 12.8; \frac{2n - 2s}{3n + 3s}$$

$$\text{is } = \frac{24}{804}. \text{ To reduce this value of } x \text{ to degrees we must multiply it by}$$

60, since a great circle was made  $= 6$ : it gives  $1^{\circ} 48' 27''$  as the internal limit of the trade-wind. This is too small by  $2^{\circ} 11' 33''$ . But the value which we have found is only that of the sine of the arc intercepted between the equator and the internal limit; the arc itself would be somewhat greater; besides, the proportion between the heat of the two segments is an assumed quantity, and may probably be greater than their difference in bulk: and one reason for this may be the great proportion of land in the northern compared with the southern segment. See the *Journal de Physique*, Mai 1791.

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of the sun. For this reason, when the sun approaches the tropic of Cancer, India, China, and the adjacent countries, become much hotter than the ocean which washes their southern coasts. The air over them becomes rarefied and ascends, while colder air rushes in from the Indian Ocean to supply its place. As this current of air moves from the equator northward, it must, for a reason already explained, assume the appearance of a south-west wind; and this tendency eastward is increased by the situation of the countries to which it flows. This is the cause of the south-west monsoon, which blows during summer in the northern parts of the Indian Ocean. Between Borneo and the coast of China its direction is almost due north, because the country to which the current is directed lies rather to the west of north; a circumstance which counteracts its greater velocity.

In winter, when the sun is on the south side of the equator, these countries become cool, and the north-east trade-wind resumes its course, which, had it not been for the interference of these countries, would have continued the whole year.

As the sun approaches the tropic of Capricorn, it becomes almost perpendicular to New Holland: that continent is heated in its turn, the air over it is rarefied, and colder air rushes in from the north and west to supply its place. This is the cause of the north-west monsoon, which blows from October to April from the third to the tenth degree of south latitude. Near Sumatra its direction is regulated by the coast: this is the case also between Africa and Madagascar.

The same cause which occasions the monsoons gives rise to the winds which blow on the west coasts of

Africa and America. The air above the land is hotter and rarer, and consequently lighter than the air above the sea; the sea air therefore flows in, and forces the lighter land atmosphere to ascend.

The same thing will account for the phenomena of the sea and land breezes. During the day, the cool air of the sea, loaded with vapours, flows in upon the land, and takes the place of the rarefied land air. As the sun declines, the rarefaction of the land air is diminished: thus an equilibrium is restored. As the sea is not so much heated during the day as the land, neither is it so much cooled during the night; because it is constantly exposing a new surface to the atmosphere. As the night approaches, therefore, the cooler and denser air of the hills (for where there are no hills there are no sea and land breezes) falls down upon the plains, and pressing upon the now comparatively lighter air of the sea, causes the land-breeze.

And of the  
sea and land  
breezes.

The rarefied air which ascends between the second and fifth degrees of north latitude has been shewn to be the principal cause of the trade-winds. As this air ascends, it must become gradually colder, and consequently heavier; it would therefore descend again if it were not buoyed up by the constant ascent of new rarefied air. It must therefore spread itself to the north and south, and gradually mix in its passage with the lower air; and the greater part of it probably does not reach far beyond the  $30^{\circ}$ , which is the external limit of the trade-wind. Thus there is a constant circulation of the atmosphere in the torrid zone; it ascends near the equator, diffuses itself toward the north and south, descends gradually as it approaches the  $30^{\circ}$ , and returning again towards the equator, performs the same circuit.



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Cause of  
south-west  
winds,

If the attraction of the moon and the diurnal motion of the sun have any effect upon the atmosphere, and that they have some effect can hardly be disputed, there must be a real motion of the air westwards within the limits of the trade-winds. The consequence of this westerly current is an easterly current on its north and south side, as has been demonstrated by D'Alembert. Hence the frequency of south-west winds over the Atlantic Ocean and the western parts of Europe.

It seems probable too that air is generated at the equator, either in consequence of the decomposition of water or of some other cause. Hence the reason that south-west winds are so frequent, particularly in summer, and that they extend over a greater tract of country than most other winds which blow in the temperate zones. What has been said of south-west winds, holds equally with regard to north-west winds in the south temperate zone.

And north-  
east winds.

After south-west winds have blown for some time, a great quantity of air will be accumulated at the pole, at least if they extend over all the northern hemisphere: and it appears from comparing the tables kept by some of our late navigators in the Northern Pacific Ocean with similar tables kept in this island, that this is sometimes the case so far as relates to the Atlantic and Pacific Oceans. When this accumulation becomes great, it must, from the nature of fluids, and from the elasticity of air, press with a considerable and increasing force on the advancing air; so that in time it becomes stronger than the south-west wind. This will occasion at first a calm, and afterwards a north wind; which will become gradually easterly as it advances southwards, from its not assuming immediately the velocity



of the earth. The mass of the atmosphere will be increased in all those places over which this north-east wind blows: this is confirmed by the almost constant rise of the barometer during a north-east wind.

Whatever tends to increase the bulk of the atmosphere near the pole, must tend also to increase the frequency of north-east winds; and if there be any season when this increase takes place more particularly, that season will be most liable to these winds. During winter the northern parts of Europe are covered with snow, which is melted in the beginning of summer, when the heat of the sun becomes more powerful. Great quantities of vapour are during that time raised, which will augment both the bulk and weight of the atmosphere; especially if part of this vapour be converted into air. Hence north-east winds are most prevalent during May and June\*.

If water be decomposed in the atmosphere and hydrogen gas evolved, that gas, from its small specific gravity, must accumulate near the poles, and be mixed with the common air of the atmosphere, or with oxygen gas, if any be set at liberty. Now may not the appearance of the aurora borealis be owing to the union of oxygen and hydrogen by the intervention of the electric fluid?

South-west wind occasioned by the decomposition of the atmosphere at the pole.

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\* The frequency of north-east winds during these months is the greatest defect in the climate of Scotland, and is felt indeed severely over all Great Britain. In the united states of America, these winds keep pace with the clearing of the land. Some time ago, in Virginia, they did not reach farther than Williamsburgh; now they reach to Richmond, which is situated considerably farther west, and are even beginning to be felt still farther within the country (Jefferson's *State of Virginia*, p. 128.) Might it not be possible then to prevent the frequency of these winds in this country, by planting trees along the whole east coast?

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That it is an electrical phenomenon at least, can hardly be doubted. Artificial electricity is much strengthened during an aurora, as Mr Volta and Mr Canton have observed; and the magnetic needle moves with the same irregularity during an aurora that has been observed in other electrical phenomena, as we learn from Bergman and De la Lande. Many philosophers have attempted to demonstrate, that auroræ boreales are beyond the earth's atmosphere; but the very different results of their calculations evidently prove that they were not possessed of sufficient data.

If this conjecture be true, part of the atmosphere near the poles must at times be converted into water. This would account for the long continuance of south-west winds at particular times: when they do so, a decomposition of the atmosphere is going on at the pole. It would render this conjecture more probable, if the barometer fell always when a south-west wind continues long.

If this hypothesis be true, a south-west wind ought always to blow after auroræ boreales; and we are informed by Mr Winn \* that this is actually the case. This he found never to fail in 23 instances. He observed also, that when the aurora was bright, the gale came on within 24 hours, but did not last long; but if it was faint and dull, the gale was longer in beginning and less violent, but it continued longer. This looks like a confirmation of the above conjecture. Bright auroræ are probably nearer than those which are dull. Now, if the aurora borealis be attended with a decomposition of a quantity of air, that part of the atmosphere which is nearest

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\* *Phil. Trans.* for 1772.

must first rush in to supply the defect, and the motion will gradually extend itself to more distant parts. Just as if a hole were bored in the end of a long vessel filled with water; the water nearest the hole would flow out immediately, and it would be some time before the water at the other end of the vessel began to move. The nearer we are to the place of precipitation, the sooner will we feel the south-west wind. It ought therefore to begin sooner after a bright aurora, because it is nearer than a dull and faint one. Precipitations of the atmosphere at a distance from the pole cannot be so great as those which take place near it; because the cold will not be sufficient to condense so great a quantity of hydrogen: south-west winds, therefore, ought not to last so long after bright as after dull auroræ. Winds are more violent after bright auroræ, because they are nearer the place of precipitation; just as the water near the hole in the vessel runs swifter than that which is at a considerable distance.

If these conjectures have any foundation in nature, there are two sources of south-west winds; the first has its origin in the trade-winds, the second in precipitations of the atmosphere near the pole. When they originate from the first cause, they will blow in countries farther south for some time before they are felt in those which are farther north; but the contrary will take place when they are owing to the second cause. In this last case, too, the barometer will sink considerably; and it actually does so constantly after auroræ, as we are informed by Mr Madison \*, who paid particular attention to this subject. By keeping accurate meteorological tables

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\* *Philad. Trans.* ii. 142.

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Two sources of north-east winds.

in different latitudes, it might easily be discovered whether these consequences be true, and consequently whether the above conjectures be well or ill grounded.

There are also two sources of north-east winds; the first is an accumulation of air at the pole, the second a precipitation of the atmosphere in the torrid zone. For the discovery of this last cause we are indebted to Dr Franklin. In 1740 he was prevented from observing an eclipse of the moon at Philadelphia by a north-east storm, which came on about seven o'clock in the evening. He was surprised to find afterwards that it had not come on at Boston till near eleven o'clock: and upon comparing all the accounts which he received from the several colonies of the beginning of this and other storms of the same kind, he found it to be always an hour later the farther north-east, for every 100 miles.

“ From hence (says he) I formed an idea of the course of the storm, which I will explain by a familiar instance. I suppose a long canal of water stopped at the end by a gate. The water is at rest till the gate is opened; then it begins to move out through the gate, and the water next the gate is first in motion, and moves on towards the gate; and so on successively, till the water at the head of the canal is in motion, which it is last of all. In this case all the water moves indeed towards the gate; but the successive times of beginning the motion are in the contrary way, viz. from the gate back to the head of the canal. Thus, to produce a north-east storm, I suppose some great rarefaction of the air in or near the gulf of Mexico; the air rising thence has its place supplied by the next more northern, cooler, and therefore denser and heavier air; a suc-



cessive current is formed, to which our coast and inland mountains give a north-east direction \*."

Currents of air from the poles naturally, as has been observed, assume a north-east direction as they advance southwards; because their diurnal motion becomes less than that of the earth. Various circumstances, however, may change this direction, and cause them to become north, or even north-west, winds. The south-west winds themselves may often prove sufficient for this; and violent rains, or great heat, by lessening or rarefying the atmosphere in any country, will produce the same effect in countries to the westwards when north winds happen to be blowing.

In North America, the north-west winds become gradually more frequent as we advance northwards. The east coast of this continent, where the observations were made from which this conclusion was drawn, is alone cultivated; the rest of the country is covered with wood. Now cultivated countries are well known to be warmer than those which are uncultivated; the earth in the latter is shaded from the sun, and never heated by his rays. The air, therefore, in the interior parts of America, must be constantly colder than near the east coast. This difference will hardly be perceptible in the southern parts, because there the influence of the sun is very powerful; but it will become gradually greater as we advance northwards, because the influence of the sun diminishes, and the continent becomes broader. Hence north-west winds ought to become more frequent upon the east coast as we advance northwards; and they will probably cease to blow so often

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\* Franklin's *Philosophical Letters*, p. 389.



## Book I.

East and  
west winds.

as soon as the whole continent of North America becomes cultivated.

Such appear to be the causes which produce the more general winds that prevail in the torrid and temperate zones. The east and west winds, when they are not partial and confined to a very small portion of the atmosphere, seem to be nothing else but currents of air brought from the north or south by the causes already mentioned, and prevented from proceeding farther by contrary currents. If these currents have come from the north, they will assume the appearance of east winds; because their diurnal motion will be less than that of the more southern latitudes over which they are forced to remain stationary. The southern currents will become west winds for a contrary reason. This will furnish us with a reason for the coldness of east winds compared with west winds. If this account be true, there ought very frequently to be a west wind in a latitude to the south of those places where an east wind blows. This might easily be determined by keeping accurate registers of the winds in different latitudes, and as nearly as possible under the same meridian; and upon the result of these observations the truth or falsehood of the above conjecture must finally rest.

Partial  
winds.

Besides these more general winds, there are others which extend only over a very small part of the earth. These originate from many different causes. The atmosphere is composed of three different substances, air, vapour, and carbonic acid; to which may be added water. Great quantities of each of these ingredients are constantly changing their aerial form, and combining with various substances; or they are separating from other bodies, assuming the form of air, and

mixing with the atmosphere. Partial voids, therefore, and partial accumulations, must be continually taking place in different parts of the atmosphere, which will occasion winds varying in direction, violence, and continuance, according to the suddenness and the quantity of air destroyed or produced. Besides these there are many other ingredients constantly mixing with the atmosphere, and many partial causes of condensation and rarefaction in particular places. To these, and other causes probably hitherto unknown, are to be ascribed all those winds which blow in any place besides the general ones already explained; and which, as they depend on causes hitherto at least reckoned contingent, will probably for ever prevent uniformity and regularity in the winds. All these causes, however, may, and probably will, be discovered; the circumstances in which they will take place, and the effects which they will produce, may be known; and whenever this is the case, the winds of any place may in some measure be reduced to calculation.

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## SECT. V.

## OF ATMOSPHERICAL ELECTRICITY.

AIR is one of those bodies which have received the name of *electric*, because they are capable of being positively or negatively charged with electric matter. It not only contains that portion of electricity which seems necessary to the constitution of all terrestrial bodies, but it is liable also to be charged negatively or posi-

## Book I.

Electricity  
of the at-  
mosphere.

tively when electricity is abstracted or introduced by means of conducting bodies. These different states must occasion a variety of phenomena, and in all probability contribute very considerably to the various combinations and decompositions which are continually going on in air. The electrical state of the atmosphere, then, is a point of considerable importance, and has with great propriety occupied the attention of philosophers ever since Dr Franklin demonstrated that thunder is occasioned by the agency of electricity.

1. The most complete set of observations on the electricity of the atmosphere were made by Professor Becaria of Turin. He found the air almost always positively electrical, especially in the day-time and in dry weather. When dark or wet weather clears up, the electricity is always negative. Low thick fogs rising into dry air carry up a great deal of electric matter.

2. In the morning, when the hygrometer indicates dryness equal to that of the preceding day, positive electricity obtains even before sunrise. As the sun gets up, this electricity increases more remarkably if the dryness increases. It diminishes in the evening.

3. The mid-day electricity of days equally dry is proportional to the heat.

4. Winds always lessen the electricity of a clear day, especially if damp.

5. For the most part, when there is a clear sky and little wind, a considerable electricity arises after sunset at dew falling.

6. Considerable light has been thrown upon the sources of atmospherical electricity by the experiments of Saussure and other philosophers. Air is not only electrified by friction like other electric bodies, but the

state of its electricity is changed by various chemical operations which often go on in the atmosphere. Evaporation seems in all cases to convey electric matter into the atmosphere; and Saussure has ascertained that the quantity of electricity is much increased when water is decomposed, as when water is dropt on a red hot iron. On the other hand, when steam is condensed into vesicular vapour, or into water, the air becomes negatively electric. Hence it would seem that electricity enters as a component part into water; that it separates when water is decomposed or expanded into steam, and is reunited when the steam is condensed again into water.

Farther, Mr Canton has ascertained that dry air, when heated, becomes negatively electric, and positive when cooled, even when it is not permitted to expand or contract: and the expansion and contraction of air also occasions changes in its electric state.

Thus there are four sources of atmospheric electricity known: 1. Friction; 2. Evaporation; 3. Heat and cold; 4. Expansion and contraction: not to mention the electricity evolved by the melting, freezing, solution, &c. of various bodies in contact of air.

Sources of  
it.

7. As air is an electric, the matter of electricity, when accumulated in any particular strata, will not immediately make its way to the neighbouring strata, but will induce in them changes similar to what is induced upon plates of glass or similar bodies piled upon each other. Therefore if a stratum of air be electrified positively, the stratum immediately above it will be negative, the stratum above that positive, and so on. Suppose now that an imperfect conductor were to come

Consequences of its  
accumulation.



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into contact with each of these strata, we know from the principles of electricity that the equilibrium would be restored, and that this would be attended with a loud noise, and with a flash of light. Clouds which consist of vesicular vapours mixed with particles of air are imperfect conductors; if a cloud therefore come into contact with two such strata, a thunder clap would follow. If a positive stratum be situated near the earth, the intervention of a cloud will, by serving as a stepping-stone, bring the stratum within the striking distance, and a thunder clap will be heard while the electrical fluid is discharging itself into the earth. If the stratum be negative, the contrary effects will take place. It does not appear, however, that thunder is often occasioned by a discharge of electric matter from the earth into the atmosphere. The accidents, most of them at least, which were formerly ascribed to this cause, are now much more satisfactorily accounted for by Lord Stanhope's *Theory of the Returning Stroke*. Neither does it appear that electricity is often discharged into the earth, as the effects of few thunder-storms are visible upon the earth; that it is so sometimes, however, is certain.

Occasions  
a kind of  
combustion  
in air.

But it is not the province of chemistry to examine in detail the phenomena of thunder; that task must be resigned to the electrical philosopher. There is one remark, however, which cannot be omitted; it is this, that, during every discharge of electricity, whether natural or artificial, through air, some change similar to combustion undoubtedly takes place. The light and the peculiar smell with which all electrical discharges are accompanied demonstrate this; for no light is perceptible



when electricity is discharged in a vacuum. What the change is which electricity produces in air, or how it produces it, are questions which, in the present state of our knowledge, are altogether insoluble. But the very extraordinary Galvanic phenomena which at present occupy the attention of philosophers, promise not only to throw light upon this important subject, but to demonstrate a much closer connection between chemistry and electricity than has hitherto been suspected.

## BOOK II.

OF

## W A T E R S.

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Book II.  
Waters

**M**ANKIND must have observed, very early, that the waters, which exist in such abundance in almost every part of the earth, differ considerably from each other in their taste and transparency, and in their fitness for serving as vehicles for food, and for the various purposes of domestic economy. These differences are occasioned by the foreign bodies which the aqueous fluid holds in solution or suspension; for water is never found native in a state of complete purity. In some cases the quantity of these foreign matters is so minute as to have but little influence on the taste or the other properties of water; but in other cases, the foreign bodies alter its properties altogether, and render it noxious, or medicinal, or unfit for the preparation of food. In the present Book I shall take a general view of the different springs and collections of water; and give an account of their properties and component parts, as far as they have been hitherto ascertained. Now waters may be

very conveniently divided into three classes: 1. Waters which may be used for dressing food, and the other purposes of domestic economy to which water is usually applied. These, for want of a better name, may be called *common water*. 2. Sea water. 3. Those waters which have been called *mineral*, in consequence of the notable quantity of mineral substances which they contain.—These three classes of waters shall form the subject of the three following Chapters.

Chap. I.  
Divisible  
into three  
classes.

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## CHAP. I.

### OF COMMON WATERS.

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GOOD water is as transparent as crystal, and entirely colourless. It has no smell, and scarcely any taste; and in general the lighter it is, so much the better. If we compare the different waters which are used for the common purposes of life with each other, and judge of them by the above standard, we shall find them to differ considerably from each other, according to the circumstances of their situation. These waters may be reduced under four heads; namely, 1. Rain water; 2. Spring and river water; 3. Well water; 4. Lake water.

1. Rain water, unless when near a town or when collected at the commencement of the rain, possesses the properties of good water in perfection, and is as free from foreign ingredients as any native water whatever.

Rain water.

## Book II.

Snow water.

How purified.

The substances which it holds in solution are *air*, *carbonic acid*, *carbonat of lime*, and, according to Bergman, it yields some traces of *nitric acid*, and a little *muriat of lime* \*. The existence of air in water was first pointed out by Boyle. Scheele has shewn that it is usually either in the state of oxygen, or at least contains an excess of oxygen, and that water absorbs oxygen gas in preference to common air. The quantity of air in good water does not exceed  $\frac{1}{8}$ th of the bulk. One hundred cubic inches of water contain generally about one cubic inch of carbonic acid gas. It is to the presence of these two elastic fluids that water owes its taste, and many of the good effects which it produces on animals and vegetables. Hence the vapidness of newly boiled water from which these gases are expelled. Snow water, when newly melted, is also destitute of all gaseous bodies †. Hence the reason that fish cannot live in it, as Carradori has ascertained ‡. Hassenfratz, indeed, has endeavoured to prove, that snow water holds oxygen gas in solution; but in all probability the water which he examined had absorbed air from the atmosphere.

The quantity of muriat of lime contained in rain water must be exceedingly minute; as Morvead has ascertained that rain water may be rendered sufficiently pure for chemical purposes by dropping into it a little barytic water, and then exposing it for some time to the atmosphere, and allowing the precipitate formed to deposit. According to that very accurate philosopher, the rain water which drops from the roofs of houses, after it has rained for some time, contains only a little

\* Bergman, i. 87.

† Ibid.

‡ Jour. de Phys. xlviii. 226.

sulphat of lime, which it has dissolved as it trickled over the slates \*.

Chap.-

2. The water of springs is nothing else than rain water, which, gradually filtering through the earth, collects at the bottom of declivities, and makes its way to the surface. It is therefore equally pure with rain water, provided it does not meet with some soluble body or other in its passage through the soil. But as this is almost always the case, we generally find, even in the purest spring water, a little carbonat of lime and common salt, besides the usual proportion of air and carbonic acid gas. Sometimes also it contains muriat of lime or a little carbonat of soda †. Bergman found the springs about Upsal, which are reckoned exceedingly pure, to contain the following foreign bodies:

Spring water.

- |                      |                       |
|----------------------|-----------------------|
| 1. Oxygen gas,       | 5. Common salt,       |
| 2. Carbonic acid,    | 6. Sulphat of potass, |
| 3. Carbonat of lime, | 7. Carbonat of soda.  |
| 4. Silica,           | 8. Muriat of lime.    |

The whole of these ingredients amounted at an average to 0.00004 parts; and the proportion of each of the solid bodies was as follows:

Carbonat of lime	5.0	Muriat of lime	0.5
Common salt	3.0	Sulphat of potass	0.25
Silica	0.5	Carbonat of soda	0.25

River waters may be considered as merely a collection of spring and rain water, and therefore are usually possessed of a degree of purity at least equal to these. Indeed, when their motion is rapid and their bed siliceous sand, they are generally purer than spring wa-

River water.

\* *Ann. de Chim.* xxiv. 321.

† Bergman, i. 88.



## Book II.

ter ; depositing during their motion every thing which was merely mechanically suspended, and retaining nothing more than the usual proportion of air and carbonic acid gas, and a very minute quantity of carbonated lime and common salt. When their bed is clayey, they are usually opal-coloured, in consequence of the particles of clay which they hold in suspension.

## Well water.

3. By well water is meant the water which is obtained by digging deep pits, which is not in sufficient quantity to overflow the mouth of the well ; but which may be obtained in abundance by pumping. It is essentially the same with spring water, being derived from the very same source ; but it is more liable to be impregnated with foreign bodies from the soil, in consequence of its stagnation or slow filtration. Hence the reason that well water is often of that kind which is distinguished by the name of *hard water*, because it does not dissolve soap, and cannot be used for dressing several kinds of food. These properties are owing to the great proportion of earthy salts which it holds in solution. The most common of these salts is sulphat of lime. These earthy salts have the property of decomposing common soap : their acid unites with the alkali of the soap, while the earthy basis forms with the oil a soap not soluble in water, which envelopes the soap and gives it a greasy feel. These waters may be in general cured by dropping into them an alkaline carbonat. Mr Sennebier has shewn that well water usually contains a greater proportion of carbonic acid gas than spring or river water.

## Hard waters.

## Water of lakes.

4. The water of lakes is merely a collection of rain water, spring water, and river water, and of course contains precisely the same heterogeneous salts : But it

is seldom so transparent as river water, being usually contaminated with the remains of animal and vegetable bodies which have undergone putrefaction in it. For as lake water is often nearly stagnant, it does not oppose the putrefaction of these bodies, but rather promotes it; whereas in river water, which is constantly in motion, no putrefaction takes place. Hence the reason of the slimy appearance and the brownish colour which often distinguishes lake water.

*Marsb* water contains a still greater proportion of animal and vegetable remains than lake water, because it is altogether stagnant. Moss water is strongly impregnated with those vegetable bodies which constitute mosses, and usually also contains iron.

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### OF SEA WATER.

THE Ocean is the great reservoir of water into which the lakes and rivers empty themselves, and from which is again drawn by evaporation that moisture which, falling in showers of rain, fertilizes the earth, and supplies the waste of the springs and rivers. This constant circulation would naturally dispose one to believe, *a priori*, that the waters of the ocean do not differ much from the waters of rivers and lakes: but nothing would be more erroneous than such a conclusion;

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for the sea water, as every one knows, differs materially from common water in its taste, specific gravity, and other properties. It contains a much greater proportion of saline matter, particularly of common salt, which is usually extracted from it. Indeed, if the sea were not impregnated with these saline bodies, the putrefaction of the immense mass of animal and vegetable matter which it contains would in a short time prove fatal to the whole inhabitants of the earth.

Quantity of  
sea water.

The absolute quantity of sea water cannot be ascertained, as its mean depth is unknown. Mr De la Place has demonstrated, that a depth of four leagues is necessary to reconcile the height to which the tides are known to rise in the main ocean with the Newtonian theory of the tides\*. If we suppose this to be the mean depth, the quantity of water in the ocean must be immense. Even on the supposition that its mean depth is not greater than the fourth part of a mile, its solid contents (allowing its surface to be three-fourths of that of the superficies of the earth) would be 32,058,939 $\frac{3}{4}$  cubic miles.

Its proper-  
ties.

Sea water has a very disagreeable bitter taste, at least when taken from the surface or near the shore; but when brought up from great depths, its taste is only saline†. Hence we learn that this bitterness is owing to the animal and vegetable bodies with which it is mixed near the surface. Its specific gravity varies from 1.0269 to 1.0285‡. It does not freeze till cooled down to zero of Fahrenheit's scale.

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\* *Mem. Par.* 1776. p. 213.

† Bergman, i. 180.

‡ Bladh, Kirwan's *Geological Essays*, p. 355.

It has been ascertained by the experiments of different chemists \*, and especially by those of Bergman, that sea water consists of water holding in solution muriat of soda, muriat of magnesia, and sulphat of lime ; besides the animal and vegetable bodies with which it is occasionally contaminated. The average quantity of saline ingredients is  $\frac{1}{28}$ . Bergman found water taken up from the depth of 60 fathoms, near the Canaries, by Dr Sparrman, to contain  $\frac{1}{24}$ . Lord Mulgrave found the water at the back of Yarmouth sands to contain about  $\frac{1}{32}$  part. From the analysis of Bergman, it appears that the relative proportions of these saline contents are as follows :

30.911 common salt  
6.222 muriat of magnesia  
1.000 sulphat of lime

Therefore, according to this analysis, 100 parts of sea water are composed of 96.00 water

Composition

3.25 common salt  
0.64 muriat of soda  
0.11 sulphat of lime

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100.00

As far as experiment has gone, the proportion of saline contents does not differ much, whatever be the latitude in which the water of the ocean is examined. Lord Mulgrave, in north latitude  $80^{\circ}$ , and 60 fathoms under ice, found the saline contents of sea water 0.0354 ; in latitude  $74^{\circ}$ , he found them 0.036 ; in latitude  $60^{\circ}$ , 0.034. Pages found sea water taken up in north latitude  $45^{\circ}$  and  $39^{\circ}$  to contain 0.04 of saline contents ;

In different places.

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\* Monnet, Lavoisier, Baumé, &c. have published analyses of sea water.

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and Beaumé obtained by analysis, from water taken up by Pages in north latitude  $34^{\circ}$  and  $14^{\circ}$  exactly the same proportions of saline matter. In southern latitudes Pages found the following proportions of saline matters :

Latitude.	Saline Matter.
$49^{\circ} 50'$ . . . . .	0.0416
$46^{\circ} 0'$ . . . . .	0.045
$40^{\circ} 30'$ . . . . .	0.04
$25^{\circ} 54'$ . . . . .	0.04
$20^{\circ} 0'$ . . . . .	0.039
$1^{\circ} 16'$ . . . . .	0.035

From the experiments made by Bladh on the specific gravity of sea water in different latitudes, it appears that the water contains more salt at the tropics than towards the equator.

If we were acquainted with the proportion between the saline contents of sea water and its specific gravity, it would be easy in all cases to ascertain the quantity of saline matter merely by taking the specific gravity of the water we wish to examine. This would require a set of experiments on purpose ; dissolving in pure water different quantities of the salts contained in sea water in the proportions which they bear to each other, and ascertaining the specific gravity of every such solution. Dr Watson has given us a Table for ascertaining that point, as far as common salt is concerned ; and as the salt which he used was not perfectly pure, but contained a mixture of the different salts usually found in the sea, we may consider it as very nearly determining the proportion of saline contents in sea water as far as it goes. This TABLE therefore I shall here insert \*.

Specific gravity of water holding different proportions of salt in solution.

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\* Watson's *Chemical Essays*, v. 91.



Proport. of Salt.	Specific Gravity.	Proport. of Salt.	Specific Gravity.	Proport. of Salt.	Specific Gravity.
0	1.000	$\frac{1}{24}$	1.032	$\frac{1}{108}$	1.007
$\frac{1}{24}$	1.206	$\frac{1}{23}$	1.029	$\frac{1}{107}$	1.006
$\frac{1}{23}$	1.160	$\frac{1}{22}$	1.027	$\frac{1}{106}$	1.005
$\frac{1}{22}$	1.121	$\frac{1}{21}$	1.025	$\frac{1}{105}$	1.004
$\frac{1}{21}$	1.107	$\frac{1}{20}$	1.024	$\frac{1}{104}$	1.003
$\frac{1}{20}$	1.096	$\frac{1}{19}$	1.023	$\frac{1}{103}$	1.0029
$\frac{1}{19}$	1.087	$\frac{1}{18}$	1.020	$\frac{1}{102}$	1.0023
$\frac{1}{18}$	1.074	$\frac{1}{17}$	1.019	$\frac{1}{101}$	1.0018
$\frac{1}{17}$	1.059	$\frac{1}{16}$	1.015	$\frac{1}{100}$	1.0017
$\frac{1}{16}$	1.050	$\frac{1}{15}$	1.014	$\frac{1}{99}$	1.0014
$\frac{1}{15}$	1.048	$\frac{1}{14}$	1.013	$\frac{1}{98}$	1.0008
$\frac{1}{14}$	1.045	$\frac{1}{13}$	1.012	$\frac{1}{97}$	1.0006
$\frac{1}{13}$	1.040	$\frac{1}{12}$	1.009		

This Table was calculated at a temperature between 46° and 55°; but Mr Kirwan has reduced part of it to the temperature of 62°, in order to compare it with the specific gravities of sea water taken at that temperature, or at least reduced to it. The specific gravities, thus altered by Kirwan, are as follows:

Proportion of Salt.

Specific Gravity at 62°.

$\frac{1}{24}$	1.0283
$\frac{1}{23}$	1.0275
$\frac{1}{22}$	1.0270
$\frac{1}{21}$	1.0267
$\frac{1}{20}$	1.0250
$\frac{1}{19}$	1.0233
$\frac{1}{18}$	1.0185
$\frac{1}{17}$	1.0033
$\frac{1}{16}$	1.0105
$\frac{1}{15}$	1.004
$\frac{1}{14}$	1.0023

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This Table will enable us to ascertain the saline contents of sea water in different parts of the Atlantic and Indian Oceans, from the following TABLE of the specific gravity of sea water in different parts of these oceans, constructed by Bladh, and reduced by Kirwan, to the temperature of  $62^{\circ}$  \*.

Specific gravity of sea water in different places.

LATITUDE.	LONGITUDE †.	Sp. Gr. at $62^{\circ}$ .
North.	East.	
$59^{\circ} 39'$	$8^{\circ} 48'$	1.0272
$57 18$	$18 48$	1.0269
	West.	
$57 1$	$1 22$	1.0272
$54 00$	$4 45$	1.0271
$44 32$	$2 04$	1.0276
	East.	
$44 07$	$1 00$	1.0276
$40 41$	$0 30$	1.0276
$34 40$	$1 18$	1.0280
$29 50$	$0 00$	1.0281
	West.	
$24 00$	$2 32$	1.0284
$18 28$	$3 24$	1.0281
$16 36$	$3 37$	1.0277
$14 56$	$3 46$	1.0275
$10 30$	$3 49$	1.0272
$5 50$	$3 28$	1.0274
$2 20$	$3 26$	1.0271
$1 25$	$3 30$	1.0273
South.		
$0 16$	$3 40$	1.0277
$5 10$	$6 00$	1.0277
$10 00$	$6 05$	1.0285
$14 40$	$7 00$	1.0284
$20 06$	$5 30$	1.0285
$25 45$	$2 22$	1.0281
	East.	
$30 25$	$7 12$	1.0279
$37 37$	$68 13$	1.0276

\* Kirwan's *Geol. Essays*, p. 350.

† The Lon. is counted from Teneriffe.

From this Table, compared with the last, we learn, that the ocean contains most salt between south latitude  $10^{\circ}$  and  $20^{\circ}$ ; the saline contents amounting to rather more than  $\frac{1}{44}$ . The quantity of salt between north latitude  $18^{\circ}$  and  $34^{\circ}$  is rather less than  $\frac{1}{44}$ : at the equator it is nearly  $\frac{1}{55}$ . The proportion of salt is least of all in north latitude  $57^{\circ}$ , where it amounts to little more than  $\frac{1}{57}$ .

From the experiments of Wilcke, we learn that the Baltic contains much less salt than the ocean; that the proportion of its salt is increased by a west wind, and still more by a north west wind. The specific gravity of the Baltic water, ascertained by this philosopher under these different circumstances, and reduced by Mr Kirwan to the temperature of  $62^{\circ}$ , is exhibited in the following TABLE:

Of the Baltic.

## Specific Gravity.

1.0039 Wind at E.

1.0067 Ditto at W.

1.0118 Storm at W.

1.0098 Wind at N.W.

From this Table it appears that the proportion of salt in the Baltic, when an east wind prevails, is only  $\frac{1}{108}$ ; and that this proportion is doubled by a westerly storm: a proof not only that the saltiness of the Baltic is derived from the neighbouring ocean, but that storms have a much greater effect upon the waters of the ocean than has been supposed\*. The Euxine and Caspian Seas, if we believe Tournefort, are less salt than the ocean†; but it is probable that the Mediterranean is at least as salt as the Atlantic.

\* Kirwan's *Geological Essays*, p. 356. † Tournefort's *Voyages*, ii. 410.

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The Dead

The water of the *Dead Sea* differs exceedingly from sea water. Its specific gravity is 1.2403; and it is saturated with salt containing no less than 44.4 *per cent.* of saline matter. According to the analysis of Lavoisier, it is composed of

55.60 water

38.15 muriat of lime and of magnesia

6.25 common salt

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100.00 \*

The water of this lake, therefore, ought to be distinguished from sea-water; and might with propriety be included among *mineral* waters.

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## CHAP III.

### OF MINERAL WATERS.

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Mineral  
waters ex-  
plained.

ALL waters which are distinguished from common water by a peculiar smell, taste, colour, &c. and which in consequence of these properties cannot be applied to the purposes of domestic economy, have been distinguished by the appellation of *mineral waters*. These occur more or less frequently in different parts of the earth, constituting wells, springs, or fountains; sometimes of the temperature of the soil through which they

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\* *Mem. Par.* 1778, p. 69.

pass, sometimes warm, and in some cases even at the boiling temperature. Many of these mineral springs attracted the attention of mankind in the earliest ages, and were resorted to by those who laboured under diseases, and employed by them either externally or internally as a medicine. But it was not till towards the end of the seventeenth century that any attempt was made to detect the ingredients of which these waters were composed, or to discover the substances to which they owed their properties.

Mr Boyle may be considered as the first person who pointed out the method of examining water. He first ascertained the existence of air in it, and pointed out a number of tests, by means of which conjectures might be made concerning the saline bodies which the water examined held in solution. In 1665, Dominic du Clos attempted to examine the different mineral waters in France. He employed almost all the re-agents recommended by Boyle, and likewise added several of his own. In 1680, Hierne published a set of experiments on the mineral waters of Sweden. Soon after various improvements were introduced by Regis, Didier, Burlet, and Homberg; and in 1726 Boulduc pointed out a method of precipitating several of the saline contents of water by means of alcohol. But it was not till after the discovery of carbonic acid by Dr Black, that any considerable progress was made in ascertaining the composition of mineral waters. That subtle acid which is so often contained in them, and which serves as a solvent to many of the earths and even metallic bodies, had thwarted all the attempts of former chemists to detect the composition of these liquids. Since the discovery of that acid, the analysis of mineral waters has advanced

Attempts  
to analyse  
them.



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with great rapidity, in consequence, chiefly, of the admirable dissertation on the analysis of mineral waters published by Bergman in 1778. Since that period much has been done by the labours of Gioanetti, Black, Klaproth, Westrum, Fourcroy, Brezé, Kirwan, and many other eminent chemists. So that notwithstanding the difficulty of the subject, scarcely any branch of chemistry has made greater progress, or is farther advanced than the knowledge of mineral waters.

Substances  
found in  
them.

The substances hitherto found in mineral waters amount to about 38, and may be reduced under the four following heads: 1. Air and its component parts, oxygen and azotic gas. 2. Acids. 3. Alkalies and earths. 4. Salts.

1. Air.

I. 1. Air is contained in by far the greater number of mineral waters: its proportion does not exceed  $\frac{1}{10}$ th of the bulk of the water.

2. Oxygen gas was first detected in waters by Scheele. Its quantity is usually inconsiderable; and it is incompatible with the presence of sulphurated hydrogen gas or iron.

3. Azotic gas was first detected in Buxton water by Dr Pearson. Afterwards it was discovered in Harrogate waters by Dr Garnet, and in those of Lemington Priors by Mr Lambe.

2. Acids.

II. The only acids hitherto found in waters, except in combination with a base, are the four following; carbonic, sulphurous, boracic, and sulphurated hydrogen gas.

I. Carbonic acid was first discovered in Pyrmont water by Dr Brownrigg. It is the most common ingredient in mineral waters, 100 cubic inches of the wa-

ter generally containing from 6 to 40 cubic inches of this acid gas. According to Westrum, 100 cubic inches of Pyrmont water contain 187 cubic inches of it, or almost double its own bulk.

2. Sulphurous acid has been observed in several of the hot mineral waters in Italy, which are in the neighbourhood of volcanoes.

3. The boracic acid has also been observed in some lakes in Italy.

4. Sulphurated hydrogen gas constitutes the most conspicuous ingredient in those waters which are distinguished by the name of hepatic or sulphureous.

III. The only alkali which has been observed in mineral waters, uncombined, is soda; and the only earthy bodies are silica and lime. 3. Alkalies and earths.

1. Dr Black detected soda in the hot mineral waters of Geyzer and Rykum in Iceland; but in most other cases the soda is combined with carbonic acid.

2. Silica was first observed in waters by Bergman. It was afterwards detected in those of Geyzer and Rykum by Dr Black, and in those of Carlsbad by Klaproth. Hassenfratz observed it in the waters of Pougues, and Brezé in those of Pu. It has been found also in many other mineral waters.

3. Lime is said to have been found uncombined in some mineral waters; but this has not been proved in a satisfactory manner.

IV. The only salts hitherto found in mineral waters are the following *sulphats, nitrats, muriats, carbonats,* and *hydrosulphurets*: 4. Salts.

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1. Sulphat of soda	15. Muriat of lime
2. ammonia	16. magnesia
3. lime	17. alumina
4. magnesia	18. manganese
5. alumina	19. Carbonat of potass
6. iron	20. soda
7. copper	21. ammonia
8. Nitrat of potass	22. lime
9. lime	23. magnesia
10. magnesia	24. alumina
11. Muriat of potass	25. iron
12. soda	26. Hydrosulph. of lime
13. ammonia	27. potass
14. barytes	28. And likewise borax.

Of these genera the carbonats and muriats occur by far most commonly, and the nitrats most rarely.

1. Sulphat of soda is not uncommon, especially in those mineral waters which are distinguished by the epithet *saline*.

2. Sulphat of ammonia is found in mineral waters near volcanoes.

3. Sulphat of lime is exceedingly common in water. Its presence seems to have been first detected by Dr Lister in 1682.

4. Sulphat of magnesia is almost constantly an ingredient in those mineral waters which have purgative properties. It was detected in Epsom waters in 1610, and in 1696 Dr Grew published a treatise on it.

5. Alum is sometimes found in mineral waters, but it is exceedingly rare.

6. and 7. Sulphat of iron occurs sometimes in volcanic mineral waters, and has even been observed in

other places. But sulphat of copper is only found in the waters which issue from copper mines.

8. Nitre has been found in some springs in Hungary; but it is exceedingly uncommon.

9. Nitrat of lime was first detected in water by Dr Home of Edinburgh in 1756. It is said to occur in some springs in the sandy deserts of Arabia.

10. Nitrat of magnesia is said to have been found in some springs.

11. Muriat of potass is uncommon; but it has lately been discovered in the mineral springs of Uhleaborg in Sweden by Julin.

12. Muriat of soda is so exceedingly common in mineral waters, that hardly a single spring has been analysed without detecting some of it.

13. Muriat of ammonia is uncommon; but it has been found in some mineral springs in Italy and in Siberia.

14. Muriat of barytes is still more uncommon; but its presence in mineral waters has been announced by Bergman.

15. and 16. Muriats of lime and magnesia are common ingredients.

17. Muriat of alumina has been observed in waters by Dr Withering; but it is very uncommon.

18. Muriat of manganese was mentioned by Bergman as sometimes occurring in mineral waters. It has lately been detected by Lambe in the waters of Lemington Priors; but in an extremely limited proportion.

19. The presence of carbonat of potass in mineral waters has been mentioned by several chemists: if it does occur, it must be in a very small proportion.

20. But carbonat of soda is, perhaps, the most com-

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mon ingredients of these liquids, if we except common salt and carbonat of lime.

21. Carbonat of ammonia has been discovered in waters; but it is uncommon.

22. Carbonat of lime is found in almost all waters, and is usually held in solution by an excess of acid. It appears from the different experiments of chemists, as stated by Mr Kirwan, and especially from those of Berthollet, that water saturated with carbonic acid is capable of holding in solution 0.002 of carbonat of lime. Now water saturated with carbonic acid at the temperature of  $50^{\circ}$ , contains very nearly 0.002 of its weight of carbonic acid. Hence it follows that carbonic acid, when present in such quantity as to saturate water, is capable of holding its own weight of carbonat of lime in solution. Thus we see that 1000 parts by weight of water, when it contains two parts of carbonic acid, is capable of dissolving two parts of carbonat of lime. When the proportion of water is increased, it is capable of holding the carbonat of lime in solution, even when the proportion of carbonic acid united with it is diminished. Thus 24,000 parts of water are capable of holding two parts of carbonat of lime in solution, even when they contain only one part of carbonic acid. The greater the proportion of water the smaller a proportion of carbonic acid is necessary to keep the lime in solution; and when the water is increased to a certain proportion, no sensible excess of carbonic acid is necessary. It ought to be remarked also, that water, how small a quantity soever of carbonic acid it contains, is capable of holding carbonat of lime in solution, provided the weight of the carbonic acid present exceed that of



the lime \*. These observations apply equally to the other earthy carbonats held in solution by mineral waters.

23. Carbonat of magnesia is also very common in mineral waters, and is almost always accompanied by carbonat of lime.

24. Carbonat of alumina is said to have been found in waters; but its presence has not been properly ascertained.

25. But carbonat of iron is by no means uncommon; indeed it forms the most remarkable ingredient in those waters which are distinguished by the epithet of *chalybeate*.

26. and 27. The hydrosulphurets of lime and of soda have been frequently detected in those waters which are called sulphureous or hepatic.

28. Borax exists in some lakes in Persia and Thibet; but the nature of these waters has not been ascertained †.

Besides these substances, certain vegetable and animal matters have been occasionally observed in mineral waters. But in most cases these are rather to be considered in the light of accidental mixtures than of real component parts of the waters in which they occur.

5. Vegeta-  
ble and ani-  
mal mat-  
ters.

From the above enumeration, we are enabled to form a pretty accurate idea of the substances which occur in mineral waters; but this is by no means sufficient to make us acquainted with these liquids. No mineral water contains all of these substances. Seldom are there more than five or six of them present together, and hardly ever do they exceed the number of eight or

\* Kirwan on Mineral Waters, p. 15.

† Ibid. p. 8. &c.

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ten. The proportion, too, in which they enter into mineral waters is generally small, and in many cases extremely so. Now in order to understand the nature of mineral waters, it is necessary to know the substances which most usually associate together, and the proportion in which they commonly associate. In the greater part of mineral waters there is usually some substance present which, from its greater proportion or its greater activity, stamps, as it were, the character of the water, and gives it those properties by which it is most readily distinguished. This substance of course claims the greatest attention, while the other bodies which enter in a smaller proportion may vary or even be absent altogether, without producing any sensible change in the nature of the water. This circumstance enables us to divide mineral waters into classes, distinguished by the peculiar substance which predominates in each. Accordingly they have been divided into four classes; namely,

Mineral  
waters di-  
vided into  
four classes.

- |                |             |
|----------------|-------------|
| 1. Acidulous,  | 3. Hepatic, |
| 2. Chalybeate, | 4. Saline.  |

Let us take a view of each of these classes.

## 1. Acidulous.

1. The acidulous waters contain a considerable proportion of carbonic acid. They are easily distinguished by their acid taste, and by their sparkling like champaign wine when poured into a glass. They contain almost constantly some common salt, and in general also a greater or smaller proportion of the earthy carbonats.

## 2. Chalybeate.

2. The chalybeate waters contain a portion of iron, and are easily distinguished by the property which they have of striking a black with the tincture of nutgalls. The iron is usually held in solution by carbonic acid.

It very often happens that this acid is in excess; in which case the waters are not only chalybeate but acidulous. This is the case with the waters of Spa and Pyrmont. In some instances the iron is in the state of a sulphat. The waters holding the sulphat of iron cannot well be applied to medicinal uses: they may be readily distinguished by the property which they have of continuing to strike a black with tincture of nutgalls even after being boiled and filtered; whereas boiling decomposes the carbonat of iron, and causes its base to precipitate.

3. The hepatic or sulphureous waters are those which contain sulphurated hydrogen gas. These waters are easily distinguished by the odour of sulphurated hydrogen gas which they exhale, and by the property which they have of blackening silver and lead. The nature of the waters belonging to this class long puzzled chemists. Though they often deposite sulphur spontaneously, yet no sulphur could be artificially separated from them. The secret was at last discovered by Bergman. These waters are of two kinds: in the first the sulphurated hydrogen is uncombined; in the second it is united to lime or an alkali. They are frequently also impregnated with carbonic acid, and usually contain some muriats or sulphats.

4. Saline waters are those which contain only salts in solution, without iron or carbonic acid in excess. They may be distinguished into four different orders. The waters belonging to the first order contain salts whose base is lime, and generally either the carbonat or the sulphat. They are known by the name of hard waters, and have but a slight disagreeable taste. The waters belonging to the second order are those in which

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common salt predominates. They are readily recognized by their salt taste, and like sea water usually contain some magnesian and calcareous salts. The waters of the third order contain sulphat of magnesia. They have a bitter taste and are purgative. Finally, the waters of the fourth order are alkaline, containing carbonat of soda. They are easily distinguished by the property which they have of tinging vegetable blues green.

Such is a short view of the different classes of mineral waters. A pretty accurate notion may be formed of the salts which most commonly associate, and of the proportions of each, from the following TABLE, which exhibits a synoptical view of the component parts of a considerable number of mineral waters as analysed by different chemists.

	Water.	Gases.		Carbonates of			Muriats of			Sulphats of			Alu- Re- mina. sin.			
		Oxy- gen.	Cubic inches.	Azo- tic.	Soda.	Lime.	Mag.	Iron.	Soda.	Lime.	Mag.	Pot- ass.		Soda.	Lime.	Mag.
Seltzer <sup>a</sup> . . .	8949	.435	13.068	—	5.22	78.3	6.32	—	13.74	—	—	—	—	—	—	—
Spa <sup>a</sup> . . . . .	8933	—	9.8	—	1.85	1.85	4.35	0.70	0.21	—	—	—	—	—	—	—
Pyrmont <sup>a</sup> . . .	8950	—	19.6	—	—	4.3	9.8	0.70	1.7	—	—	—	8.38	5.44	—	—
Aix la Chap. <sup>a</sup>	894	—	—	—	15.25	5.98	—	—	6.21	—	—	—	—	—	—	—
Medvi <sup>a</sup> . . . .	8933	—	6.53	—	—	—	—	0.92	—	0.11	—	—	—	—	—	—
Carlsbad <sup>b</sup> . . .	25320	—	50.	—	38.5	12.5	—	0.1 $\frac{1}{4}$	32.5	—	—	66.75	—	—	2.25	—
Lem. Priors <sup>c</sup>	5816	—	.5	—	—	—	—	.75	430.	—	11.5	15.2	112.	—	—	—
Pougues <sup>d</sup> . . .	9216	—	16.7	—	10.4	12.4	1.2	—	2.2	—	8.0	—	33.3	15.8	—	0.35
Enghien <sup>e</sup> . . .	92160	—	18.5	—	—	21.4	1.35	—	2.4	—	—	—	14.03	—	—	—
Luf . . . . .	36864	—	5.	—	—	10.22	—	—	36.74	9.25	—	—	—	—	—	—
Geyzer <sup>g</sup> . . . .	10000	—	—	—	0.95 <sup>*</sup>	—	—	—	2.46	—	—	1.46	—	—	—	0.23
Uhleaborg <sup>h</sup> . .	42250	—	10.	—	—	1.9	—	1.2	5.7	—	—	—	0.8	—	—	5.4
Teplisz <sup>i</sup> . . . .	22540	—	—	—	13.25	16.5	—	32.5	61.3	28.5	—	—	—	—	—	1.7
Kilburn <sup>k</sup> . . .	138240	—	84.	—	—	2.4	1.25	.3 $\frac{3}{8}$	6.0	.6	12.8	28.2	13.0	91.0	—	15.1
																.6

<sup>a</sup> Bergman.

<sup>b</sup> Klaproth.

<sup>c</sup> Lambe, *Manch.* v. 174.

<sup>d</sup> Hassenfratz, *Ann. de Chim.* i. 81.

<sup>e</sup> Fourcroy, *Ibid.* vi. 172.

<sup>f</sup> Brezé, *Ibid.* x. 44.

<sup>g</sup> Pure soda.

<sup>h</sup> Black.

<sup>i</sup> Jahn, *Ibid.* i. 331.

<sup>k</sup> Schmeisser, *Phil. Trans.* lxxii. 127.



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## CHAP. IV.

### OF THE METHOD OF ANALYSING WATERS.

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THE analysis of waters, or the art of ascertaining the different substances which they hold in solution, and of determining the proportion of these substances, is one of the most difficult things in chemistry. The difficulty arises, not only from the diversity of the bodies which occur in waters, but from the very minute quantities of some of the ingredients. Though many attempts had been made to analyse particular waters, and several of these were remarkably well conducted, no general mode of analysis was known till Bergman published his *Treatise on Mineral Waters* in 1778. His admirable tract carried the subject all at once to a very high degree of perfection. The Bergmannian method has been followed by succeeding chemists, to whom we are indebted not only for a great number of very accurate analyses of mineral waters, but likewise for several improvements in the mode of conducting the analysis. Mr Kirwan has in 1799 published an *Essay on the general analysis of waters*, no less valuable than that of Bergman; containing all that has hitherto been done on the subject, and enriched by the numerous experiments of Mr Kirwan himself, which are equally important and well conducted. Mr Kirwan has given a new method of analysis, which will probably be adopted hereafter; not

only because it is shorter and easier than the Bergmanian, but because it is susceptible of a greater degree of accuracy. I propose in this Chapter to give an account of this method.

The analysis of waters resolves itself into two different branches: 1. The method of ascertaining all the different bodies contained in the water which we are examining. 2. The method of determining the exact proportion of each of these ingredients. These two branches shall form the subject of the two following Sections.

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## SECT. I.

### METHOD OF DETERMINING THE INGREDIENTS OF WATERS.

THE different bodies which are dissolved and combined in water, are discovered by the addition of certain substances to the water which is subjected to examination. The consequence of the addition is some change in the appearance of the water; and this change indicates the presence or the absence of the bodies suspected. The substances thus employed are distinguished by the name of *tests*, and are the instruments by means of which the analysis of water is accomplished. They were first introduced into chemistry by Boyle, and were gradually increased by succeeding chemists: but Bergman was the first who ascertained with precision the degree of confidence which can be placed in the different tests. They still continued rather uncertain and precarious,

Tests

## Book II.

till Mr Kirwan shewed how they might be combined and arranged in such a manner as to give certain and precise indications whether or not any particular substance constitutes a component part of water. Let us consider by what means the presence or the absence of all the different substances which occur in waters may be ascertained.

For gases,

I. The gaseous bodies contained in water are obtained by boiling it in a retort luted to a pneumatic apparatus. The method of separating and examining these different bodies shall be described in the next Section.

Carbonic acid,

II. The presence of *carbonic acid*, not combined with a base, or combined in excess, may be detected by the following tests: 1. Lime water occasions a precipitate soluble with effervescence in muriatic acid. 2. The infusion of litmus is *reddened*; but the red colour gradually disappears, and may be again restored by the addition of more of the mineral water \*. 3. When boiled it loses the property of reddening the infusion of litmus.

Mineral acids,

III. The mineral acids when present, uncombined in water, give the infusion of litmus a permanent red, even though the water has been boiled. Bergman has shewn that paper, stained with litmus, is reddened when dipt into water containing  $\frac{1}{3333}$  of sulphuric acid.

Sulphurated hydrogen,

IV. Water containing sulphurated hydrogen gas is distinguished by the following properties: 1. It exhales

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\* When the carbonic acid is uncombined with a base, it reddens the infusion of litmus, though it amounts to no more than one-sixteenth of the bulk of the water which contains it. When it is combined in excess with a base, it must amount to one-sixth of the bulk of the water to produce that effect.—See Kirwan on *Mineral Waters*, p. 35.

the peculiar odour of sulphurated hydrogen gas. 2. It reddens the infusion of litmus fugaciously. 3. It blackens paper dipt into a solution of lead, and precipitates the nitrat of silver black or brown.

V. Alkalies, and *alkaline* and *earthy carbonats*, are distinguished by the following tests: 1. The infusion of turmeric, or paper stained with turmeric, is rendered *brown* by alkalies, or reddish-brown if the quantity be minute. This change is produced when the soda in waters amounts only to  $\frac{1}{1000}$  part\*. 2. Paper stained with Brazil wood, or the infusion of Brazil wood, is rendered blue: But this change is produced also by the alkaline and earthy carbonats. Bergman ascertained that water containing  $\frac{1}{9999}$  part of carbonat of soda renders paper stained with Brazil wood blue†. 3. Litmus paper reddened by vinegar is restored to its original blue colour. This change is produced by the alkaline and earthy carbonats also. 4. When these changes are fugacious, we may conclude that the alkali is ammonia.

Alkaline  
and earthy  
carbonats,

VI. Fixed alkalies exist in water which occasions a precipitate with muriat of magnesia after being boiled. Volatile alkali may be distinguished by the smell, or it may be obtained in the receiver by distilling a portion of the water gently, and then it may be distinguished by the above tests.

Fixed alkalis,

VII. Earthy and metallic carbonats are precipitated

Earthy and  
metallic  
carbonats,

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\* The same change is produced by lime-water; but pure lime very seldom indeed occurs in mineral waters. It is needless to observe, that the alkalies produce the same effect on turmeric, whether they be pure or in the state of carbonats. The earthy carbonats have no effect on turmeric.

† Sulphat of lime likewise renders Brazil wood blue.

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Iron,

by boiling the water containing them; except carbonat of magnesia, which is only precipitated imperfectly.

VIII. Iron is discovered by the following tests:

1. The addition of tincture of nutgalls gives water containing iron a purple or black colour. This test indicates the presence of a very minute portion of iron. If the tincture has no effect upon the water after boiling, though it colours it before, the iron is in the state of a carbonat. The following observations of Westrum on the colour which iron gives to nutgalls, as modified by other bodies, deserve attention.

A violet indicates an alkaline carbonat or earthy salt.

Dark purple indicates other alkaline salts.

Purplish red indicates sulphurated hydrogen gas\*.

Whitish and then black indicates sulphat of lime.

2. The prussian alkali occasions a blue precipitate in water containing iron. If an alkali be present, the blue precipitate does not appear unless the alkali be saturated with an acid.

Sulphuric acid,

IX. Sulphuric acid exists in waters which form a precipitate with the following saline solutions:

1. Muriat, nitrat, or acetite of barytes
2. . . . . strontian
3. . . . . lime
4. Nitrat or acetite of lead.

Of these the most powerful by far is muriat of barytes, which is capable of detecting the presence of sulphuric acid uncombined, when it does not exceed the millionth part of the water. Acetite of lead is next in point of power. The muriats are more powerful than the nitrats. The calcareous salts are least powerful. All

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\* Or rather manganese, according to Kirwan.



these tests are capable of indicating a much smaller proportion of uncombined sulphuric acid than when it is combined with a base \*. To render muriat of barytes a certain test of sulphuric acid, the following precautions must be observed: 1. The muriat must be diluted. 2. The alkalies, or alkaline carbonats, if the water contain any, must be previously saturated with muriatic acid. 3. The precipitate must be insoluble in muriatic acid. 4. If boracic acid be suspected, muriat of strontian must be tried, which is not precipitated by boracic acid. 5. The hydrosulphurets precipitate barytic solution, but their presence is easily discovered by the smell.

X. Muriatic acid is detected by nitrat of silver, which occasions a white precipitate, or a cloud in water containing an exceedingly minute portion of this acid. To render this test certain, the following precautions are necessary: 1. The alkalies or carbonats must be previously saturated with nitric acid. 2. Sulphuric acid, if any be present, must be previously removed by means of nitrat of barytes. 3. The precipitate must be insoluble in nitric acid.

XI. Boracic acid is detected by means of acetite of lead, with which it forms a precipitate insoluble in acetous acid. But to render this test certain, the alkalies and earths must be previously saturated with acetous acid, and the sulphuric and muriatic acids removed by means of acetite of strontian and acetite of silver.

XII. Barytes is detected by the insoluble white precipitate which it forms with diluted sulphuric acid.

XIII. Lime is detected by means of oxalic acid, which

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\* Kirwan on *Mineral Waters*, p. 65.

## Book II.

occasions a white precipitate in water, containing a very minute proportion of this earth. To render this test decisive, the following precautions are necessary: 1. The mineral acids, if any be present, must be previously saturated with an alkali. 2. Barytes, if any be present, must be previously removed by means of sulphuric acid. 3. Oxalic acid precipitates magnesia but very slowly, whereas it precipitates lime instantly.

Magnesia  
and alumina.

XIV. Magnesia and alumina. The presence of these earths is ascertained by the following tests: 1. Pure ammonia precipitates them both, and no other earth, provided the carbonic acid has been previously separated by a mineral alkali and boiling. 2. Lime-water precipitates only these two earths, provided the carbonic acid be previously removed, and the sulphuric acid also, by means of nitrat of barytes.

The alumina may be separated from the magnesia after both have been precipitated together, either by boiling the precipitate in pure potass, which dissolves the alumina and leaves the magnesia; or the precipitate may be dissolved in muriatic acid precipitated by an alkaline carbonat, dried in the temperature of a  $100^{\circ}$ , and then exposed to the action of diluted muriatic acid, which dissolves the magnesia without touching the alumina.

## Silica.

XV. Silica may be ascertained by evaporating a portion of the water to dryness, and redissolving the precipitate in muriatic acid. The silica remains behind undissolved.

Such is the method of detecting the different substances commonly found in waters. But as these different substances are almost always combined together, so as to constitute particular salts, it is not sufficient to know in

general what the substances are which are found in the water we are examining; we must know also in what manner they are combined. Thus it is not sufficient to know that lime forms an ingredient in a particular water, we must know also the acid with which it is united. Mr Kirwan first pointed out how to accomplish this difficult task by means of tests. Let us take a short view of his method.

I. To ascertain the presence of the different sulphats.

The sulphats which occur in water are seven, but one of these, namely, *sulphat of copper*, is so uncommon, that it may be excluded altogether. The same remark applies to sulphat of ammonia. It is almost unnecessary to observe, that no sulphat need be looked for unless both its acid and base have been previously detected in the water.

1. Sulphat of soda may be detected by the following method: Free the water to be examined of all earthy sulphats by evaporating it to one half, and adding lime-water as long as any precipitate appears. By this means the earths will all be precipitated except lime, and the only remaining earthy sulphat will be sulphat of lime, which will be separated by evaporating the liquid till it becomes concentrated, and then dropping into it a little alcohol, and after filtration adding a little oxalic acid.

1. Alkaline.

With the water thus purified, mix a solution of lime. If a precipitate appears either immediately or on the addition of a little alcohol, it is a proof that sulphat of potass or of soda is present. Which of the two may be determined by mixing some of the purified water with acetite of barytes. Sulphat of barytes precipitates.

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Filter and evaporate to dryness. Digest the residuum in alcohol. It will dissolve the alkaline acetite. Evaporate to dryness, and the dry salt will deliquesce if it be acetite of potass, but effloresce if it be acetite of soda.

## 2. Calcareous.

2. Sulphat of lime may be detected by evaporating the water suspected to contain it to a few ounces. A precipitate appears, which, if it be sulphat of lime, is soluble in 500 parts of water; and the solution affords a precipitate with the muriat of barytes, oxalic acid, carbonat of magnesia, and with alcohol.

## 3. Alum.

3. Alum may be detected by mixing carbonat of lime with the water suspected to contain it. If a precipitate appears it indicates the presence of alum, or at least of sulphat of alumina; provided the water contains no muriat of barytes or metallic sulphats. The first of these salts is incompatible with alum. The second may be removed by the alkaline prussiate. When a precipitate is produced in water by muriat of lime, carbonat of lime, and muriat of magnesia, we may conclude that it contains alum or sulphat of alumina.

## 4. Magnesian.

4. Sulphat of magnesia may be detected by means of hydrosulphuret of strontian, which occasions an immediate precipitate with this salt and with no other; provided the water be previously deprived of alum, if any be present, by means of carbonat of lime, and provided also that it contains no uncombined acid, not even carbonic acid.

## 5. Of iron.

5. Sulphat of iron is precipitated from water by alcohol, and then it may be easily recognised by its properties.

## Muriats

II. To ascertain the presence of the different muriats.

The muriats found in waters amount to eight or to



nine, if muriat of iron be included. The most common by far is muriat of soda.

1. Muriat of soda and of potass may be detected by the following method: Separate the sulphuric acid by alcohol and nitrat of barytes. Decompose the earthy nitrats and muriats by adding sulphuric acid. Expel the excess of muriatic and nitric acids by heat. Separate the sulphats thus formed by alcohol and barytic water. The water thus purified can contain nothing but alkaline nitrats and muriats. If it forms a precipitate with acetite of silver, we may conclude that it contains muriat of soda or of potass. To ascertain which, evaporate the liquid thus precipitated to dryness; dissolve the acetite in alcohol. Evaporate to dryness. The salt will deliquesce if it be acetite of potass, but effloresce if it be acetite of soda.

1. Alkaline.

2. Muriat of barytes may be detected by sulphuric acid, as it is the only barytic salt hitherto found in waters.

2. Barytic.

3. Muriat of lime may be detected by the following method: Free the water of sulphat of lime and other sulphats, by evaporating it to a few ounces, mixing it with spirit of wine, and adding last of all nitrat of barytes as long as any precipitate appears. Filter off the water, evaporate to dryness, treat the dry mass with alcohol. Evaporate the alcohol to dryness and dissolve the residuum in water. If this solution gives a precipitate with acetite of silver and oxalic acid, it *may* contain muriat of lime. It must contain it in that case, if, after being treated with carbonat of lime, it gives no precipitate with ammonia. If it does, separate the lime by means of oxalic acid, filter and distil with a gentle heat. If the liquid in the receiver gives a precipitate with nitrat of silver, muriat of lime existed in the water.

3. Calcareous.



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 4. Magnesian.

4. Muriat of magnesia may be detected by separating all the sulphuric acid by means of nitrat of barytes. Filter, evaporate to dryness, and treat the dry mass with alcohol. Evaporate the alcohol solution to dryness, and dissolve the residuum in water. The muriat of magnesia, if the water contained any, will be found in this solution. Let us suppose that, by the tests formerly described, the presence of muriatic acid and of magnesia in this solution has been ascertained. In that case, if carbonat of lime affords no precipitate, and if sulphuric acid and evaporation, together with the addition of a little alcohol, occasion no precipitate, the solution contains only muriat of magnesia. If these tests give precipitates, we must separate the lime which is present by sulphuric acid and spirit of wine, and distil off the acid with which it was combined. Then the magnesia is to be separated by the oxalic acid and alcohol; and the acid with which it was united is to be distilled off. If the liquid in the retort gives a precipitate with nitrat of silver, the water contains muriat of magnesia.

5. Aluminous.

5. Muriat of alumina may be discovered by saturating the water, if it contain an excess of alkali, with nitric acid, and separating the sulphuric acid by means of nitrat of barytes. If the liquid thus purified gives a precipitate with carbonat of lime, it contains muriat of alumina. The muriat of iron or of manganese, if any be present, is also decomposed, and the iron precipitated by this salt. The precipitate may be dissolved in muriatic acid, and the alumina, iron, and manganese, if they be present, may be separated by the rules laid down in the next Book.

Nitrats.

III. To ascertain the presence of the different nitrats.

The nitrats but seldom occur in waters ; when they do, they may be detected by the following rules : Chap. IV.

1. Alkaline nitrats may be detected by freeing the water examined from sulphuric acid by means of acetite of barytes, and from muriatic acid by acetite of silver. Evaporate the filtered liquid, and treat the dry mass with alcohol ; what the alcohol leaves can consist only of the alkaline nitrats and acetite of lime. Dissolve it in water. If carbonat of magnesia occasions a precipitate, lime is present. Separate the lime by means of carbonat of magnesia. Filter and evaporate to dryness, and treat the dried mass with alcohol. The alcohol now leaves only the alkaline nitrats, which may be easily recognised, and distinguished by their respective properties.

1. Alkaline.

2. Nitrat of lime. To detect this salt, concentrate the water, and mix it with alcohol to separate the sulphats. Filter and distil off the alcohol ; then separate the muriatic acid by acetite of silver. Filter, evaporate to dryness, and dissolve the residuum in alcohol. Evaporate to dryness, and dissolve the dry mass in water. If this last solution indicates the presence of lime by the usual tests, the water contained nitrat of lime.

2. Calcareous.

3. To detect nitrat of magnesia, the water is to be freed from sulphats and muria exactly as described in the last paragraph. The liquid thus purified is to be evaporated to dryness, and the residuum treated with alcohol. The alcohol solution is to be evaporated to dryness, and the dry mass dissolved in water. To this solution potass is to be added as long as any precipitate appears. The solution, filtered, and again evaporated to dryness, is to be treated with alcohol. If it leaves a residuum consisting of nitre (the only residuum

3. Magnesian.

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Incompati-  
ble salts.

which it can leave), the water contained nitrat of magnesia.

Such are the methods by which the presence of the different saline contents of waters may be ascertained. The labour of analysis may be considerably shortened, by observing that the following salts are incompatible with each other, and cannot exist together in water except in very minute proportions\*.

SALTS.	INCOMPATIBLE WITH
1. Fixed alkaline sulphats . . . . .	{ Nitrats of lime and magnesia, Muriats of lime and magnesia.
2. Sulphat of lime . . . . .	{ Alkalies, Carbonat of magnesia, Muriat of barytes.
3. Alum . . . . .	{ Alkalies, Muriat of barytes, Nitrat, muriat, carbonat of lime, Carbonat of magnesia.
4. Sulphat of magnesia . . . . .	{ Alkalies, Muriat of barytes, Nitrat and muriat of lime.
5. Sulphat of iron . . . . .	{ Alkalies, Muriat of barytes, Earthy carbonats.
6. Muriat of barytes . . . . .	{ Sulphats, Alkaline carbonats, Earthy carbonats.
7. Muriat of lime . . . . .	{ Sulphats, except of lime, Alkaline carbonats, Carbonat of magnesia.

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\* See Kirwan on *Mineral Waters*, passim.

8. Muriat of magne-  
sia . . . . .
9. Nitrat of lime
- { Alkaline carbonats,  
Alkaline sulphats.
- { Alkaline carbonats,  
Carb. of magn. and alumina,  
Sulphats, except of lime.

Besides the substances above described, there is sometimes found in water a quantity of bitumen combined with alkali, and in the state of soap: In such waters acids occasion a coagulation; and the coagulum collected on a filter discovers its bituminous nature by its combustibility.

Water also sometimes contains *extractive matter*; the presence of which may be detected by means of nitrat of silver. The water suspected to contain it must be freed from sulphuric and nitric acid by means of nitrat of lead. After this, if it gives a brown precipitate with nitrat of silver, we may conclude that extractive matter is present\*.

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## SECT. II.

### METHOD OF DETERMINING THE PROPORTION OF THE INGREDIENTS.

THE proportion of saline ingredients, held in solution by any water, may be in some measure estimated from its specific gravity. The lighter a water is, the less saline matter does it contain; and, on the other hand, the

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\* Westrum.

## Book II.

Formula for  
finding the  
saline con-  
tents of  
water.

heavier it is, the greater is the proportion of saline contents. Mr Kirwan has pointed out a very ingenious method of estimating the saline contents of a mineral water whose specific gravity is known; so that the error does not exceed one or two parts in the hundred. The method is this : Subtract the specific gravity of pure water from the specific gravity of the mineral water examined (both expressed in whole numbers), and multiply the remainder by 1.4. The product is the saline contents in a quantity of the water denoted by the number employed to indicate the specific gravity of distilled water. Thus let the water be of the specific gravity 1.079, or in whole numbers 1079. Then the specific gravity of distilled water will be 1000. And  $1079 - 1000 \times 1.4 = 110.6 =$  saline contents in 1000 parts of the water in question ; and consequently 11.06 in 100 parts of the same water \*. This formula will often be of considerable use, as it serves as a kind of standard to which we may compare our analysis. The saline contents indicated by it are supposed to be freed from their water of crystallization ; in which state only they ought to be considered, as Mr Kirwan has very properly observed, when we speak of the saline contents of a mineral water.

Having by this formula ascertained pretty nearly the proportion of saline contents in the water examined, and having by the tests described in the last Section determined the particular substances which exist in it, let us now proceed to ascertain the proportion of each of these ingredients.

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\* Kirwan on *Mineral Waters*, p. 145.



I. The different aerial fluids ought to be first separated and estimated. For this purpose a retort ought to be filled two-thirds with the water, and connected with a jar full of mercury, standing over a mercurial trough. Let the water be made to boil for a quarter of an hour. The aerial fluids will pass over into the jar. When the apparatus is cool, the quantity of air expelled from the water may be determined either by bringing the mercury within and without the jar to a level; or if that cannot be done, by reducing the air to the proper density by the formulas given in the first Chapter of the last Book. The air of the retort ought to be carefully subtracted, and the jar must be divided into cubic inches and tenths.

To estimate  
the gaseous  
bodies.

The only gaseous bodies contained in water are common air, oxygen gas, azotic gas, carbonic acid, sulphurated hydrogen gas, and sulphurous acid. The last two never exist in water together. The presence of either of them must be ascertained previously by the application of the proper tests. If sulphurated hydrogen gas be present, it will be mixed with the air contained in the glass jar, and must be separated before that air be examined. For this purpose, the jar must be carried into a tub of warm water, and nitric acid introduced, which will absorb the sulphurated hydrogen. The residuum is then to be again put into a mercurial jar and examined.

If the water contain sulphurous acid, this previous step is not necessary. Introduce into the air a solution of pure potass, and agitate the whole gently. The carbonic acid and sulphurous acid gas will be absorbed, and leave the other gases. Estimate the bulk of this residuum; this, subtracted from the bulk of the whole,

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will give the bulk of the carbonic acid and sulphurous acids absorbed.

Evaporate the potass slowly nearly to dryness, and leave it exposed to the atmosphere. Sulphat of potass will be formed, which may be separated by dissolving the carbonat of potass by means of diluted muriatic acid and filtering the solution. 100 grains of sulphat of potass indicate 30 grains of sulphurous acid, or 42.72 cubic inches of that acid in the state of gas. The bulk of sulphurous acid gas ascertained by this method, subtracted from the bulk of the gas absorbed by the potass, gives the bulk of the carbonic acid gas. Now 100 cubic inches of carbonic acid, at the temperature of  $60^{\circ}$  and barometer 30 inches, weigh 46.393 grains. Hence it is easy to ascertain its weight.

The air which remains after the separation of the carbonic acid gas is to be examined by the different eudiometrical methods described in the last Book.

When a water contains sulphurated hydrogen gas, the bulk of this gas is to be ascertained in the following manner: Fill three-fourths of a jar with the water to be examined, and invert it in a water trough, and introduce a little nitrous gas. This gas, mixing with the air in the upper part of the jar, will form nitrous acid, which will render the water turbid, by decomposing the sulphurated hydrogen and precipitating sulphur. Continue to add nitrous gas at intervals as long as red fumes appear, then turn up the jar and blow out the air. If the hepatic smell continues, repeat this process. The sulphur precipitated indicates the proportion of hepatic gas in the water; one grain of sulphur indicating the presence of 3.33 cubic inches of that gas.

II. After having estimated the gaseous bodies, the

Chap. IV.

To estimate  
the earthy  
carbonats.

next step is to ascertain the proportions of the earthy carbonats. For this purpose it is necessary to deprive the water of its sulphurated hydrogen, if it contains any. This may be done, either by exposing it to the air for a considerable time, or by treating it with litharge. A sufficient quantity of the water thus purified (if necessary) is to be boiled for a quarter of an hour and filtered when cool. The earthy carbonats remain in the filter.

The precipitate thus obtained may be carbonat of lime, of magnesia, of iron, of alumina; or even sulphat of lime. Let us suppose all of these substances to be present together. Treat the mixture with diluted muriatic acid, which will dissolve the whole except the alumina and sulphat of lime. Dry this residuum in a red heat, and note the weight. Then boil it in carbonat of soda: saturate the soda with muriatic acid, and boil the mixture for half an hour. Carbonat of lime and alumina precipitate. Dry this precipitate, and treat it with acetous acid. The lime will be dissolved and the alumina will remain. Dry it and weigh it. Its weight subtracted from the original weight gives the proportion of sulphat of lime.

The muriatic solution contains lime, magnesia, and iron. Add ammonia as long as a reddish precipitate appears. The iron and part of the magnesia are thus separated. Dry the precipitate, and expose it to the air for some time in a heat of  $200^{\circ}$ ; then treat it with acetous acid to dissolve the magnesia, which solution is to be added to the muriatic solution. The iron is to be redissolved in muriatic acid, precipitated by an alkaline carbonat dried and weighed.

Add sulphuric acid to the muriatic solution as long

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as any precipitate appears, then heat the solution and concentrate. Heat the sulphat of lime thus obtained to redness, and weigh it. 100 grains of it are equivalent to 70 of carbonat of lime dried. Precipitate the magnesia by means of carbonat of soda. Dry it and weigh it. But as part remains in solution, evaporate to dryness, and wash the residuum with a sufficient quantity of distilled water to dissolve the muriat of soda and the sulphat of lime, if any be still present. What remains behind is carbonat of magnesia. Weigh it, and add its weight to the former. The sulphat of lime, if any, must also be separated and weighed.

Estimation  
of the mi-  
neral acids,

III. Let us now consider the method of ascertaining the proportion of mineral acids or alkalies, if any be present uncombined. The acids which may be present (omitting the gaseous) are the sulphuric, muriatic, and boracic.

1. The proportion of sulphuric acid is easily determined. Saturate it with barytic water, and ignite the precipitate. 100 grains of sulphat of barytes thus formed indicate 23.5 of real sulphuric acid.

2. Saturate the muriatic acid with barytic water, and then precipitate the barytes by sulphuric acid. 100 parts of the ignited precipitate are equivalent to 21 grains of real muriatic acid.

3. Precipitate the boracic acid by means of acetite of lead. Decompose the borat of lead by boiling it in sulphuric acid. Evaporate to dryness. Dissolve the boracic acid in alcohol, and evaporate the solution; the acid left behind may be weighed.

And alk-  
aline carbo-  
nats.

4. To estimate the proportion of alkaline carbonat present in a water containing it, saturate it with sulphuric acid, and note the weight of real acid necessary.

Now 100 grains of real sulphuric acid saturate 121.48 potass, and 78.32 soda.

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IV. Let us now consider the method of ascertaining the proportion of the different sulphats. These are six in number; the alkaline sulphats, and those of lime, alumina, magnesia, and iron.

To estimate sulphats.

1. The alkaline sulphats may be estimated by precipitating their acid by means of nitrat of barytes, having previously freed the water of all other sulphats. For 170 grains of ignited sulphat of barytes indicate 100 grains of dried sulphat of soda; while 136.36 grains of sulphat of barytes indicate 100 of dry sulphat of potass.

1. Alkaline,

2. Sulphat of lime is easily estimated by evaporating the liquid containing it to a few ounces (having previously saturated the earthy carbonats with nitric acid), and precipitating the sulphat of lime by means of weak alcohol. It may be then dried and weighed.

2. Calcareous,

3. The quantity of alum may be estimated by precipitating the alumina by carbonat of lime or of magnesia (if no lime be present in the liquid). Twelve grains of the alumina heated to incandescence indicate 100 of crystallized alum, or 49 of the dried salt.

3. Aluminous,

4. Sulphat of magnesia may be estimated, provided no other sulphat be present, by precipitating the acid by means of a barytic salt, as 100 parts of ignited sulphat of barytes indicate 52.11 of sulphat of magnesia. If sulphat of lime, and no other sulphat accompany it, this last may be decomposed, and the lime precipitated by carbonat of magnesia. The weight of the lime thus obtained enables to ascertain the quantity of sulphat of lime contained in the water. The whole sulphuric acid is then to be precipitated by barytes. This gives

4. Magnesian,



## Book II.

the quantity of sulphuric acid; and subtracting the portion which belongs to the sulphat of lime, there remains that which was combined with the magnesia, from which the sulphat of magnesia may be easily estimated.

If sulphat of soda be present, no earthy nitrat or muriat can exist. Therefore, if no other earthy sulphat be present, the magnesia may be precipitated by soda, dried, and weighed; 36.68 grains of which indicate 100 grains of dried sulphat of magnesia. The same process succeeds when sulphat of lime accompanies these two sulphats; only in that case the precipitate, which consists both of lime and magnesia, is to be dissolved in sulphuric acid, evaporated to dryness, and treated with twice its weight of cold water, which dissolves the sulphat of magnesia, and leaves the other salt. Let the sulphat of magnesia be evaporated to dryness, exposed to a heat of  $400^{\circ}$ , and weighed. The same process succeeds if alum be present instead of sulphat of lime. The precipitate in that case, previously dried, is to be treated with acetous acid, which dissolves the magnesia, and leaves the alumina. The magnesia may be again precipitated, dried, and weighed. If sulphat of iron be present, it may be separated by exposing the water to the air for some days, and mixing with it a portion of alumina. Both the oxide of iron and the sulphat of alumina, thus formed, precipitate in the state of an insoluble powder. The sulphat of magnesia may then be estimated by the rules above explained.

## 5. Of iron.

5. Sulphat of iron may be estimated by precipitating the iron by means of prussic alkali, having previously determined the weight of the precipitate produced by the prussiat in a solution of a given weight of sulphat

of iron in water. If muriat of iron be also present, which is a very rare case, it may be separated by evaporating the water to dryness, treating the residuum with alcohol, which dissolves the muriat, and leaves the sulphat. Or the sulphat may be estimated with great precision by the rules laid down by Mr Kirwan\*.

V. Let us now consider the method of estimating the quantity of the different muriats which may exist in waters. Estimation  
of muriats.

If muriat of potass or of soda, without any other salt, exist in water, we have only to decompose them by nitrat of silver, and dry the precipitate; for 217.65 of muriat of silver indicate 100 of muriat of potass, and 235 of muriat of silver indicate 100 of common salt. 1. Alkaline,

The same process is to be followed if the alkaline carbonats be present; only these carbonats must be previously saturated with sulphuric acid; and we must precipitate the muriatic acid by means of sulphat of silver instead of nitrat. The presence of sulphat of soda does not injure the success of this process.

If muriat of ammonia accompany either of the fixed alkaline sulphats without the presence of any other salt, decompose the sal ammoniac by barytic water, expel the ammonia by boiling, precipitate the barytes by diluted sulphuric acid, saturate the muriatic acid with soda. The sulphat of barytes thus precipitated indicates the quantity of muriat of ammonia; 100 grains of sulphur indicating 49.09 grains of that salt. If sulphats be present in the solution, they ought to be previously separated.

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\* *On Mineral Waters*, p. 220.

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## 2. Earthy.

If common salt be accompanied by muriat of lime, muriat of magnesia, muriat of alumina, or muriat of iron, or by all of these together without any other salts, the earths may be precipitated by barytic water, and redissolved in muriatic acid. They are then to be separated from each other by the rules formerly laid down; and their weight being determined indicates the quantity of every particular earthy muriat contained in the water. For 50 grains of lime indicate 100 of dried muriat of lime; 30 grains of magnesia indicate 100 of the muriat of that earth; and 21.8 grains of alumina indicate 100 of the muriat of alumina. The barytes is to be separated from the solution by sulphuric acid, and the muriatic acid expelled by heat, or saturated with soda; the common salt may then be ascertained by evaporation, subtracting in the last case the proportion of common salt indicated by the known quantity of muriatic acid from which the earths had been separated.

When sulphats and muriats exist together, they ought to be separated either by precipitating the sulphats by means of alcohol, or by evaporating the whole to dryness, and dissolving the earthy muriats in alcohol. The salts thus separated may be estimated by the rules already laid down.

When alkaline and earthy muriats and sulphat of lime occur together, this last salt is to be decomposed by means of muriat of barytes. The precipitate ascertains the weight of sulphat of lime contained in the water. The estimation is then to be conducted as when nothing but muriats are present; only from the muriat of lime that proportion of muriat must be deducted which is known to have been formed by the infusion of the muriat of barytes.

When muriats of soda, magnesia, and alumina, are present together with sulphats of lime and magnesia, the water to be examined ought to be divided into two equal portions. To the one portion add carbonat of magnesia till the whole of the lime and alumina be precipitated. Ascertain the quantity of lime which gives the proportion of sulphat of lime. Precipitate the sulphuric acid by muriat of barytes. This gives the quantity contained in the sulphat of magnesia and sulphat of lime; subtracting this last portion, we have the quantity of sulphat of magnesia.

From the second portion of water precipitate all the magnesia and alumina by means of lime-water. The weight of these earths enables us to ascertain the weight of muriat of magnesia and of alumina contained in the water, subtracting that part of the magnesia which existed in the state of sulphat, as indicated by the examination of the first portion of water. After this estimation precipitate the sulphuric acid by barytic acid, and the lime by carbonic acid. The liquid evaporated to dryness leaves the common salt.

VI. It now only remains to explain the method of ascertaining the proportion of the nitrats which may exist in waters.

Estimation  
of nitrats.

1. When nitre accompanies sulphats and muriats without any other nitrat, the sulphats are to be decomposed by acetite of barytes, and the muriats by acetite of silver. The water, after filtration, is to be evaporated to dryness, and the residuum treated with alcohol, which dissolves the acetites, and leaves the nitre; the quantity of which may be easily estimated. If an alkali be present, it ought to be previously saturated with sulphuric or muriatic acid.

1. Alkaline,

Book II.  
2. Earthy.

2. If nitre, common salt, nitrat of lime, and muriat of lime or of magnesia, be present together, the water ought to be evaporated to dryness, and the dry mass treated with alcohol, which takes up the earthy salts. From the residuum, redissolved in water, the nitre may be separated, and estimated as in the last case. The alcohol solution is to be evaporated to dryness, and the residuum redissolved in water. Let us suppose it to contain muriat of magnesia, nitrat of lime, and muriat of lime. Precipitate the muriatic acid by nitrat of silver, which gives the proportion of muriat of magnesia and of lime. Separate the magnesia by means of carbonat of lime, and note its quantity. This gives us the quantity of muriat of magnesia. And subtracting the muriatic acid contained in that salt from the whole acid indicated by the precipitate of silver, we have the proportion of muriat of lime. Lastly, saturate the lime added to precipitate the magnesia with nitric acid. Then precipitate the whole of the lime by sulphuric acid; and subtracting from the whole of the sulphat thus formed that portion formed by the carbonat of lime added, and by the lime contained in the muriat, the residuum gives us the lime contained in the original nitrat; and 35 grains of lime form 100 of dry nitrat of lime.



## BOOK III.

OF

## MINERALS.

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ALL the solid materials of which this globe of ours is composed have received the name of *minerals*; and that branch of chemistry which treats of them is distinguished by the title of MINERALOGY. These substances without doubt must have at all times attracted the attention of mankind; because from them alone are drawn the metals, stones, and other similar substances of indispensable use. But it is only very lately that the method of ascertaining the component parts of these substances was discovered, or that it was possible to describe them so as to be intelligible to others. From the ancients no information of any consequence on these topics is to be expected. The whole science of mineralogy has been created since the year 1770, and is at present advancing towards perfection with astonishing rapidity. New minerals are every day described and analysed, collections are everywhere forming, and travels of discovery are succeeding each other without in-

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termission. The fruit of these labours has been the discovery of no less than six new earths and eight new metals ; besides a vast number of useful minerals which had been formerly unknown or disregarded.

The science of mineralogy includes under it three different topics : 1. The method of *describing* minerals with so much accuracy and precision, that they may be easily distinguished from each other. 2. *A systematic arrangement* of minerals. 3. The art of *analysing* minerals. These three topics shall form the subject of the three following Chapters.

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## CHAP. I.

### OF THE DESCRIPTION OF MINERALS.

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Nothing, at first sight, appears easier than to describe a mineral, and yet, in reality, it is attended with a great deal of difficulty. The mineralogical descriptions of the ancients are so loose and inaccurate, that many of the minerals to which they allude cannot be ascertained ; and consequently their observations, however valuable in themselves, are often, as far as respects us, altogether lost. It is obvious, that to distinguish a mineral from every other, we must either mention some peculiar property, or a collection of properties, which exist together in no other mineral. These properties must be described in terms rigidly accurate, which con-

very precise ideas of the very properties intended, and of no other properties. The smallest deviation from this would lead to confusion and uncertainty. Now it is impossible to describe minerals in this manner, unless there be a peculiar term for each of their properties, and unless this term be completely understood. Mineralogy therefore must have a language of its own; that is to say, it must have a *term* to denote every mineralogical property, and each of these terms must be accurately defined. The language of mineralogy was invented by the celebrated Werner of Freyberg, and first made known to the world by the publication of his treatise on *the external characters of minerals*. Of this language the following general description of the properties of minerals will convey an idea\*.

The properties of minerals may be divided into two classes. 1. Properties discoverable without destroying the texture of the mineral; 2. Properties resulting from the action of other bodies on it. The first class has, by Werner and his disciples, been called *external* properties, and by some French writers *physical*; the second class has been called *chemical*.

Properties  
of minerals.

The *external* properties may be arranged under the following heads:

- |                  |                |                  |
|------------------|----------------|------------------|
| 1. Figure.       | 8. Ductility.  | 14. Sound.       |
| 2. Surface.      | 9. Fracture.   | 15. Smell.       |
| 3. Transparency. | 10. Texture.   | 16. Taste.       |
| 4. Colour.       | 11. Structure. | 17. Gravity.     |
| 5. Scratch.      | 12. Fragments. | 18. Magnetism.   |
| 6. Lustre.       | 13. Feel.      | 19. Electricity. |
| 7. Hardness.     |                |                  |

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\* The fullest account of Werner's external characters which I have seen in the English language, has been given by Dr Townson in his *Philosophy of Mineralogy*.

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Figure.

I. By FIGURE is meant the shape or form which a mineral is observed to have. The *figure* of minerals is either *regular*, *particular*, or *amorphous*. 1. Minerals which assume a regular figure are said to be crystallized. The *sides* of a crystal are called *faces*; the sharp line formed by the inclination of two faces is called an *edge*; and the corner, or angle, formed by the meeting of several edges in one point, is called a *solid angle*, or simply *an angle*. Thus a cube has six faces, twelve edges, and eight angles. 2. Some minerals, though not crystallized, affect a *particular* figure. These particular figures are the following: *Globular*, like a globe; *oval*, like an oblong spheroid; *ovate*, like an egg; *cheese-shaped*, a very flattened sphere; *almond-shaped*, like an almond; *lenticular*, like a double convex lense, compressed and gradually thinner towards the edges; *cuneiform*, like a wedge; *nodulous*, having depressions and protuberances like a potatoe; *botryoidal*, like grapes closely pressed together; *dentiform*, longish and tortuous, and thicker at the bottom than the top; *wireform*, like a wire; *capillary*, like hair, finer than the preceding; *retiform*, threads interwoven like a net; *dendritic*, like a tree, having branches issuing from a common stem; *shrubform*, branches not arising from a common stem; *coraloidal*, branched like coral; *stalactitical*, like isicles; *clavated*, like a club, long, and thicker at one end than another; *fasciform*, long straight cylindrical bodies, united like a bundle of rods; *tubular*, cylindrical and hollow. 3. When minerals have neither a regular nor particular shape, they are said to be *amorphous*.

Surface.

II. By SURFACE is meant the appearance of the external surface of minerals. The *surface* is either *uneven*,

composed of small unequal elevations and depressions; *scabrous*, having very small *sharp* and rough elevations, more easily felt than seen; *drusy*, covered with very minute crystals; *rough*, composed of very minute *blunt* elevations, easily distinguishable by the feel; *scaly*, composed of very minute thin scale-like leaves; *smooth*, free from all inequality or roughness; *specular*, having a smooth polished surface like a mirror; or *streaked*, having elevated, straight, and parallel lines. This last character is confined to the *surface* of crystals. The *streaks* are either *transverse*; *longitudinal*; *alternate*, in different directions on different faces; *plumose*, running from a middle rib; or *decussated*, crossing each other.

III. By TRANSPARENCY is meant the proportion of light which minerals are capable of transmitting. They are *transparent* or *pellucid* when objects can be seen distinctly through them; *diaphanous*, when objects are seen through them indistinctly; *subdiaphanous*, when light passes but in so small a quantity that objects cannot be seen through them\*; *opaque*, when no light is transmitted. Transpa-  
rency.

When opaque minerals become transparent in water, they are called *hydrophanous*. When objects are seen double through a transparent mineral, it is said to *refract doubly*.

IV. The colours of minerals may be reduced to eight Colours classes.

\* According to Mr Kirwan's method, I have denoted these three degrees of transparency by the figures 4, 3, 2. When a mineral is subdiaphanous only at the edges, that is denoted by the figure 1. Opacity is sometimes denoted by 0.



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1. *Whites.*

Snow white. Pure white.

Reddish white. White with a light tint of red.

Yellowish white. White with a light tint of yellow.

Silver white. Yellowish white with a metallic lustre.

Greyish white. White with a light tint of black.

Greenish white. White with a light tint of green.

Milk white. White with a light tint of blue.

Tin white. Milk white of a metallic lustre.

2. *Greys.*

Bluish grey. Grey with a little blue.

Lead grey. Bluish grey with a metallic lustre.

Pearl grey. Light grey with a slight mixture of violet blue.

Smoke grey. Dark grey with a little blue and brown.

Greenish grey. Light grey tinged with green.

Yellowish grey. A light grey tinged with yellow.

Steel grey. A dark grey with a light tint of yellow and a metallic lustre.

Black grey. The darkest grey with a tint of yellow.

3. *Blacks.*

Greyish black. Black with a little white.

Brownish black. Black with a tint of brown.

Black. Pure black.

Iron black. Pure black with a small mixture of white and a metallic lustre.

Bluish black. Black with a tint of blue.

4. *Blues.*

Indigo blue. A dark blackish blue.

Prussian blue. The purest blue.

Azure blue. A bright blue with scarce a tint of red.

Smalt blue. A light blue.

Violet blue. A mixture of azure blue and carmine.

Lavender blue. Violet blue mixed with grey.

Sky blue. A light blue with a slight tint of green.

#### 5. Greens.

Verdigris green. A bright green of a bluish cast.

Seagreen. A very light green, a mixture of verdigris green and grey.

Beryl green. The preceding, but of a yellowish cast.

Emerald green. Pure green.

Grass green. Pure green with a tint of yellow.

Apple green. A light green formed of verdigris green and white.

Leek green. A very dark green with a cast of brown.

Blackish green. The darkest green, a mixture of leek green and black.

Pistachio green. Grass green, yellow and a little brown.

Olive green. A pale yellowish green with a tint of brown.

Asparagus green. The lightest green, yellowish with a little brown and grey.

#### 6. Yellows.

Sulphur yellow. A light greenish yellow.

Brass yellow. The preceding, with a little less green and a metallic lustre.

Lemon yellow. Pure yellow.

Gold yellow. The preceding with a metallic lustre.

Honey yellow. A deep yellow with a little reddish brown.

Wax yellow. The preceding, but deeper.

Pyritaceous. A pale yellow with grey.

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Straw yellow. A pale yellow, a mixture of sulphur yellow and reddish grey.

Wine yellow. A pale yellow with a tint of red.

Ochre yellow. Darker than the preceding, a mixture of lemon yellow with a little brown.

Isabella yellow. A pale brownish yellow, a mixture of pale orange with reddish brown.

Orange yellow. A bright reddish yellow, formed of lemon yellow and red.

7. *Reds.*

Aurora red. A bright yellow red, a mixture of scarlet and lemon yellow.

Hyacinth red. A high red like the preceding, but with a shade of brown.

Brick red. Lighter than the preceding, a mixture of aurora red and a little brown.

Scarlet red. A bright and high red with scarce a tint of yellow.

Copper red. A light yellowish red with the metallic lustre.

Blood red. A deep red, a mixture of crimson and scarlet.

Carmine red. Pure red verging towards a cast of blue.

Cochineal red. A deep red; a mixture of carmine with a little blue and a very little grey.

Crimson red. A deep red with a tint of blue.

Flesh red. A very pale red of the crimson kind.

Rose red. A pale red of the cochineal kind.

Peach blossom red. A very pale whitish red of the crimson kind.

Mordoré. A dark dirty crimson red; a mixture of crimson and a little brown.

Brownish red. A mixture of blood red and brown.

Chap. I.

### 8. Browns.

Reddish Brown. A deep brown inclining to red.

Clove brown. A deep brown with a tint of carmine.

Yellowish brown. A light brown verging towards ochre yellow.—

Umber brown. A light brown, a mixture of yellowish brown and grey.

Hair brown. Intermediate between yellow brown and clove brown with a tint of grey.

Tombac brown. A light yellowish brown, of a metallic lustre, formed of gold yellow and reddish brown.

Liver brown. A dark brown; blackish brown with a tint of green.

Blackish brown. The darkest brown.

Colours, in respect of intensity, are either *dark*, *deep*, *light*, or *pale*. When a colour cannot be referred to any of the preceding, but is a mixture of two, this is expressed by saying, that the prevailing one *verges* towards the other, if it has only a small tint of it; *passes* into it, if it has a greater.

V. By the SCRATCH or STREAK, is meant the mark left when a mineral is scratched by any hard body, as the point of a knife. It is either *similar*, of the same colour with the mineral; or *dissimilar*, of a different colour.

Scratch.

VI. LUSTRE, is the gloss or brightness which appears on the external surface of a mineral, or on its internal surface when fresh broken. The first is called *external*, the second *internal* lustre. Lustre is either *common*, that which most minerals possess; *silky*, like that of silk or mother-of-pearl; *waxy*, like that of wax;

Lustre.

Book III. *greasy*, like that of grease; or *metallic*, like that of metals.

As to the degree, the greatest is called *splendent*, the next *shining*, the third *dullish*; and when only a few scattered particles shine, the lustre is called *dull*\*.

Hardness. VII. I have used Mr Kirwan's figures to denote the comparative **HARDNESS** of bodies; for an explanation of which the reader is referred to Vol. I. p. 86. of this Work.

Ductility. VIII. With respect to **DUCTILITY** and **BRITTLENESS**, minerals are either *malleable*; *sectile*, capable of being cut without breaking, but not malleable; *flexile*, capable of being bent, and when bent retaining their shape; or *elastic*, capable of being bent, but recovering their former shape. Minerals destitute of these properties are *brittle*. Brittle minerals, with respect to the ease with which they may be broken, are either *very tough*, *tough*, *fragile*, or *very fragile*.

Fracture. IX. By **FRACTURE** is meant the fresh surface which a mineral displays when broken. It is either *flat*, without any general elevation or depression; or *conchoidal*, having wide extended roundish hollows and gentle risings. When these are not *very* evident, the fracture is called *flat conchoidal*; when they are small, it is called *small conchoidal*; and when of great extent, *great conchoidal*.

The fracture may also be *even*, free from all asperities; *uneven*, having many small, sharp, abrupt, irregular elevations and inequalities; and from the size of these, this fracture is denominated *coarse*, *small*, or *fine*;

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\* These four degrees have been denoted by Mr Kirwan by the figures 4, 3, 2, 1, and no lustre by 0.



*splintery*, having small, thin, half detached, sharp edged splinters, according to the size of which this fracture is denominated *coarse* or *fine*; or *rugged*, having many very minute sharp hooks, more sensible to the hand than the eye.

X. By TEXTURE is meant the internal structure or disposition of the matter of which a mineral is composed, which may be discovered by breaking it. The texture is either *compact*, without any distinguishable parts, or the appearance of being composed of smaller parts; *earthy*, composed of very minute almost imperceptible rough parts; *granular*, composed of small shapeless grains; *globuliform*, composed of small spherical bodies; *fibrous*, composed of fibres which may be *long*, *short*, *straight*, *crooked*, *parallel*, *divergent*, *stellated*, *fasciculated*, or *decussated*; *radiated*, consisting of long narrow flattish lamellæ; or *lamellar*, or *foliated*, consisting of smooth continued plates covering each other: these plates may be either *straight*, *crooked*, or *undulating*.

XI. The STRUCTURE or COMPOUND TEXTURE is the manner in which the parts that form the texture are disposed. It is either *slaty*, in straight layers like slate; *testaceous*, in incurvated layers; *concentric*, in concentric layers; or *columnar*, in columns.

The texture and structure may at first view appear the same; but in reality they are very different. Thus common slate has often the *slaty structure* and *earthy texture*. The texture of pitcoal is compact, but its structure is often *slaty*.

XII. By FRAGMENTS is meant the shape of the pieces into which a mineral breaks when struck with a hammer. They are either *cubic*; *rhomboidal*; *wedgesha-*

## Book III.

*ped*; *splintery*, thin, long, and pointed; *tabular*, thin, and broad, and sharp at the corners, as common slate; or *indeterminate*, without any particular resemblance to any other body. The *edges* of indeterminate fragments are either *very sharp*, *sharp*, *sharpish*, or *blunt*.

Feel.

XIII. By the FEEL of minerals is meant the sensation which their surfaces communicate when handled. The feel of some minerals is *greasy*, of others *dry*, &c.

Sound.

XIV. Some minerals when struck give a *clear* SOUND, as common slate; others a *dull* sound.

The SMELL, TASTE, SPECIFIC GRAVITY, and MAGNETISM of minerals, require no explanation.

With respect to ELECTRICITY, some minerals become electric when *heated*, others when *rubbed*, others cannot be rendered electric. The electricity of some minerals is *positive* or *vitreous*, of others *negative* or *resinous*.

Of the  
blow-pipe.

The CHEMICAL properties of minerals will be understood without any explanation. In detecting them, the *blow-pipe* is often of singular use, as it enables us in a few minutes to determine many points which by the usual processes would occupy a great deal of time. The blow-pipe is merely a tube ending in a cavity as fine as a small wire, through which air is forced and made to play upon the flame of a candle, by means of which the flame is concentrated and directed against small particles of the mineral to be examined, either placed upon a bit of charcoal or in a platinum or silver spoon. The air is either forced into the blow-pipe by the lungs of the experimenter, or by means of bellows attached to the blow-pipe. By thus exposing a very small portion of a mineral to the concentrated flame, we see the effect of heat upon it, and have an opportunity of trying the action of other bodies on it at a very high

temperature, as of borax, soda, microcosmic salt, &c. The properties which these experiments bring into view, enable us in many cases to ascertain the nature, and even the component parts, of a mineral.

The blow-pipe was first introduced into mineralogy by Von Swab. It was afterwards improved by Cronstedt, and still farther by Bergman. Saussure substituted a fine splinter of cyanite for charcoal, cemented a very minute portion of the mineral to be examined to the point of this splinter, and exposed it in that situation to the action of the blow-pipe. By this contrivance he was enabled to make his experiments upon very minute particles; and this enabled him to fuse many bodies formerly considered as infusible.

## CHAP. II.

SYSTEM OF MINERALOGY.  

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MINERALS may be arranged two ways, according to their external characters, and according to their chemical composition. The first of these methods has been called an *artificial* classification; the second, a *natural* one. The first is indispensably necessary for the student of nature; the second is no less indispensable for the proficient who means to turn his knowledge to account. Without the first, it is impossible to discover the *names* of minerals; and without the second, we must remain ignorant of their use.

Almost every system of mineralogy hitherto published, at least since the appearance of Werner's *external characters*, has attempted to combine these two arrangements, and to obtain at one and the same time the advantages peculiar to each. But no attempt of this kind has hitherto succeeded. Whether this be owing to any thing impossible in the undertaking, or to the present imperfect state of mineralogy, as is more probable, I do not take upon me to determine. But surely the want of success which has hitherto attended all attempts to combine the two arrangements, ought to suggest the propriety of separating them. By adhering strictly to one language, the trouble of studying two

different systems would be entirely prevented. They would throw mutual light upon each other: the artificial system would enable the student to discover the *names* of minerals; the natural would enable him to arrange them, and to study their properties and uses.

The happy arrangement of Cronstedt, together with the subsequent improvements of Bergman, Werner, Kirwan, Haüy, and other celebrated mineralogists, has brought the *natural* system of mineralogy to a considerable degree of perfection. But an *artificial* system is still a desideratum; for excepting Linnæus, whose success was precluded by the state of the science, no one has hitherto attempted it. I have elsewhere given an outline of an *artificial* system, extremely imperfect indeed, but capable, by a combination with the Wernerian characters, of being made as precise as we please\*. But such a system would be foreign to the present Work, in which our object ought certainly to be to arrange minerals according to their composition, or to give what has been called a *natural* system of mineralogy.

Avicenna, a writer of the 11th century, divided minerals into four classes; stones, salts, inflammable bodies, and metals†. This division has been, in some measure, followed by all succeeding writers. Linnæus, indeed, the first of the moderns who published a system

Division of  
minerals

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\* See the *Supplement to the Encyclopædia Britannica*, vol. ii. p. 193.

† Corpora mineralia in quatuor species dividuntur, scilicet in lapides, et in liquefactiva, sulphurea, et sales. Et horum quædam sunt raræ substantiæ et debilis compositionis, et quædam fortis substantiæ, et quædam ductibilia, et quædam non. Avicenna *de Congelatione et Conglutinatione Lapidum*, cap. iii. *Theatrum Chemicum*, t. iv. p. 997.



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of mineralogy, being guided by the external characters alone, divided minerals into three classes, *petræ*, *minera*, *fossilia* : but Avicenna's classes appear among his orders. The same remark may be made with respect to the systems of Wallerius, Wolsterdorf, Cartheuser, and Justi, which appeared in succession after the first publication of Linnæus's *Systema Naturæ*, in 1736. At last, in 1758, the system of Cronstedt appeared. He reinstated the classes of Avicenna in their place ; and his system was adopted by Bergman, Kirwan, Werner, and the most celebrated mineralogists who have written since. These classes shall be adopted in the following system, because none which are preferable have been hitherto proposed.

## Into classes.

I shall therefore divide minerals into four classes :

- |            |                  |
|------------|------------------|
| 1. Stones, | 3. Combustibles, |
| 2. Salts.  | 4. Ores.         |

The first class comprehends all the minerals which are composed chiefly or entirely of earths ; the second, all the combinations of acids and alkalies which occur in the mineral kingdom ; the third, those minerals which are capable of combustion, and which consist chiefly of sulphur, carbon, and oil ; the fourth, the mineral bodies which are composed chiefly of metals.

## CLASS I.

## EARTHS AND STONES.

THIS class may be divided into three orders. The first order comprehends all chemical combinations of earths with each other; the second order, chemical combinations of earths with acids; and the third order, mechanical mixtures of earths or stones. All the minerals belonging to the first order exhibit the same homogeneous appearance to the eye as if they were simple bodies. I shall therefore, for want of a better name, call the first order *simple*; the second order may be distinguished by the epithet of *saline*; and the third by that of *aggregates*; because most of the minerals belonging to it consist of various *simple stones*, cemented as it were together.

## ORDER I. SIMPLE STONES.

CRONSTEDT divided this order into nine genera, corresponding to nine earths; one of which he thought composed the stones arranged under each genus. The names of his genera were, *calcareæ*, *siliceæ*, *granatinaæ*, *argillaceæ*, *micaceæ*, *fluores*, *asbestinæ*, *zeolithicæ*, *magnesiæ*. All his earths were afterwards found to be com-

Cronstedt's  
genera

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Chap. II.

pounds, except the first, second, fourth, and ninth. Bergman, therefore, in his *Sciagraphia*, first published in 1782, reduced the number of genera to five; which was the number of primitive earths known when he wrote. Since that period five new earths have been discovered. Accordingly, in the latest systems of mineralogy, the genera belonging to this order are proportionally increased. Each genus is named from an earth; and they are arranged in the newest Wernerian system, which I have seen, as follows:

- |                        |                      |
|------------------------|----------------------|
| 1. Jargon genus,       | 5. Magnesian genus,  |
| 2. Siliceous genus,    | 6. Calcareous genus, |
| 3. Glucina genus,      | 7. Barytic genus,    |
| 4. Argillaceous genus, | 8. Strontian genus.  |

Mr Kirwan, in his very valuable system of mineralogy, has adopted the same genera. Under each genus, those stones are placed which are composed chiefly of the earth which gives a name to the genus, or which at least are supposed to possess the characters which distinguish that earth.

Defective.

A little consideration will be sufficient to discover that there is no natural foundation for these genera. Most stones are composed of two, three, or even four ingredients; and, in many cases, the proportion of two or more of these is nearly equal. Now, under what genus soever such minerals are arranged, the earth which gives it a name must form the smallest part of their composition. Accordingly, it has not been so much the chemical composition, as the external character, which has guided the mineralogist in the distribution of his species. The genera cannot be said properly to have any character at all, nor the species to be connected by any thing else than an arbitrary title. This defect,

which must be apparent in the most valuable systems of mineralogy, seems to have arisen chiefly from an attempt to combine together an artificial and natural system. I have ventured to form new genera for this order, according to the following rules.

Class I.  
Order I.

The only substances which enter into the minerals belonging to this order, in such quantity as to deserve attention, are the following:

New genera.

Alumina,	Zirconia,
Silica,	Yttria,
Magnesia,	Oxide of iron,
Lime,	Oxide of chromium,
Barytes,	Oxide of nickel,
Glucina,	Potass.

All those minerals which are composed of the *same* ingredients I arrange under the *same* genus. According to this plan, there must be as many genera as there are varieties of combinations of the above substances existing in nature. The varieties in the *proportion* of the ingredients constitute species. I have not imposed names upon these genera, but, in imitation of Bergman\*, have denoted each by a symbol. This symbol is composed of the first letter of every substance which enters in any considerable quantity into the composition of the minerals arranged under the genus denoted by it. Thus, suppose the minerals of a genus to be composed of *alumina*, *silica*, and *oxide of iron*, I denote the genus by the symbol *asi*. The letters are arranged according to the proportion of the ingredients; that which enters in the greatest proportion being put first, and the others in their order. Thus the genus *asi*

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\* Opusc. iv. 231.

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is composed of a considerable proportion of alumina, of a smaller proportion of silica, and contains least of all of iron. By this contrivance, the symbol of a genus contains, within the compass of a few letters, a pretty accurate description of its nature and character. Where the proportions of the ingredients vary in the same genus so much, that the letters which constitute its symbol change their place, I subdivide the genus into parts; and whenever the minerals belonging to any genus become too numerous, advantage may be taken of these subdivisions, and each of them may be formed into a separate genus. At present this seems unnecessary.

The following is a view of the different genera belonging to this order, denoted each by its symbol. Every genus is followed by the species included under it; and the whole are in the order which I mean to follow in describing them:

## I. A.

1. Sapphire
2. Corundum
3. Native alumina

## II. S.

1. Quartz
2. Flint
3. Opal
4. Pitchstone
5. Chrysoprasium

## III. L.

Native lime

## IV. AMc

Ruby

## V. AIm

Ceylanite

## VI. 1. As

1. Topaz
2. Sommite
3. Shorlite

## 2. SA

4. Rubellite
5. Hornslate
6. Hornstone
7. Chalcedony
8. Jasper
9. Tripoli

## VII. ASI

1. 1. Micarell
2. Shorl
3. Granatite
2. SAI



Class I.  
Order I.

4. Tourmaline 4. SLA

5. Argentine felspar 9. Lazulite

6. Mica XIII. SALI

7. Talc 1. Garnet

8. Basaltine 2. Pyrop

9. Hornblende 3. Melanite

10. Obsidian 4. Thummerstone

11. Petrillite 5. Prehnite

12. Felsite 6. Thallite

VIII. SNAW 7. Skorza

Pimelite XIV. AMS

IX. SAP 1. Cyanite

1. Felspar 2. MSA

2. Lepidolite 2. Serpentine

3. Leucite XV. MSAI

4. White chlorite 1. Potstone

X. SAG 2. Chlorite

1. Emerald XVI. SLAM

2. Euclase Siliceous spar

XI. SAB XVII. SAMLI

Staurolite Argillite

XII. 1. ASL XVIII. SLACMI

1. Chrysoberyl Smaragdite

2. SAL XIX. SM

2. Hyalite 1. Kiffekill

3. Edelite 2. Steatites

4. Scapolite XX. MSI

3. SAWL 1. Chrysolite

5. Zeolite 2. Jade

6. Stilbite XXI. SML

7. Chabasie 1. Asbestos

8. Analcime 2. Asbestinite

Vol. III.

E e

Class I.  
Order I.

## XXII. 1. SILM

1. Augite

2. Asbestoid

## 2. SMIL

3. Actinolite

4. Idocrase

## XXIII. SL

1. Shistose hornstone

2. Tremolite

## XXIV. Zs

Zircon

## XXV. YsI

Gadolinite

## GENUS I. A.

Sp. 1. Sapphire\*.

*Oriental ruby, sapphire, and topaz*—*Rubis d'orient* of Romé de Lisle—*Telesia* of Haüy—*Sapphire* of Delametherie.

## History.

Three stones, distinguished from each other by their colour, have been long held in high estimation on account of their hardness and beauty. These stones were known among lapidaries by the names of *ruby, sapphire, and topaz*; and the epithet *oriental* was usually added, to distinguish them from other three, known by the same names and the same colours, but very inferior in hardness and beauty. Mineralogists were accustomed to consider these stones as three distinct species, till Romé de Lisle observed that they agreed in the form of their crystals, their hardness, and most of their other properties. These observations were sufficient to constitute them one species; and accordingly they were made one species by Romé de Lisle himself, by Kirwan, and several other modern mineralogical writers. Romé de Lisle gave the species the name of *ruby*; but this has

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\* See Kirwan's *Mineralogy*, i. 250.—Gmelin's *Systema Naturæ* of Linnaeus, iii. 170.—Romé de Lisle's *Crystallographie*, ii. 212.—Bergman's *Opuscula*, ii. 72.

Genus I. A.  
Species I.

been since confined to a different mineral. This induced Haüy to invent the new word *telesia*; but the term *sapphire*, which has been appropriated to this species by Werner and Delametherie, has been adopted by mineralogists in general. I shall therefore use it in preference.

The sapphire is found in the East Indies, especially in Pegu and the island of Ceylon; and it is most commonly crystallized. The crystals are of no great size: Crystals. Their *primitive* form, according to Mr Haüy, is a regular six-sided prism, divisible in directions parallel both to its bases and its sides; and consequently giving for the form of its primitive nucleus, or of its *integrant molecule*, an equilateral three-sided prism\*. The most usual variety is a dodecahedron, in which the *telesia* appears under the form of two very long slender six-sided pyramids, joined base to base. The sides of these pyramids are isosceles triangles, having the angle at their vertex  $22^{\circ} 54'$ , and each of these at the base  $78^{\circ} 48' \frac{1}{2}$ . The inclination of a side of one pyramid to a contiguous side of the other pyramid is  $139^{\circ} 54' \frac{1}{2}$ . In some specimens the summits of the pyramids are wanting; so that the crystal has the appearance of a six-sided prism, somewhat thicker in the middle than towards the extremities. The three alternate angles at each extremity of this prism are also sometimes wanting, and a small triangular face instead of them, which renders the bases of the supposed prism nine-sided. The inclina-

\* *Ann. de Chim.* xvii. 313.

† In some instances, the angle at the vertex is  $31^{\circ}$ , those at the base  $74^{\circ} 30'$ , and the inclination of two triangles  $122^{\circ} 36'$ . See Haüy, *Ibid.*

‡ *Ibid.* and Romé de Lisle, ii. 315.

Class I.  
Order I.

tion of each of these small triangles to the base is  $122^{\circ} 18'$  \*. For figures of these crystals the reader is referred to Romé de Lisle and Haüy †.

Properties.

The texture of the sapphire is foliated, and the joints are parallel to the base of the prism ‡. Its lustre varies from 3 to 4 §. Transparency usually 3 or 4, sometimes only 2. It causes only a single refraction. Specific gravity from 4. to 4.288. Hardness from 15 to 17. It is either colourless, or red, yellow, or blue. These colours have induced lapidaries to divide the species into the three following varieties.

Varieties.

*Variety 1. Red. Oriental ruby.*—Colour carmine red, sometimes verging towards violet. Sometimes various colours appear in the same stone, as red and white, red and blue, orange red. Hardness 17. Specific gravity 4.288.

*Variety 2. Yellow. Oriental topaz.*—Colour golden yellow. Transparency 4. Hardness 15. Specific gravity 4.0106.

*Variety 3. Blue. Oriental sapphire.*—Colour Berlin blue, often so very faint that the stone appears almost colourless. Transparency 3, 4, 2. Hardness 17. Specific gravity 3.991 to 4.083 ||. This variety is not probably the same with the sapphire of the ancients. Their sapphire was distinguished by gold-coloured spots, none of which are to be seen in the sapphire of the moderns ¶.

\* Haüy, *Ann. de Chim.* xvii. 313.

† Ibid.

‡ Haüy.

§ When the kind of lustre is not specified, as in the present instance, the common is always meant.

|| Greville, Nicholson's *Journal*, iii. 11.

¶ Hill's Theophrastus, *περι των λιθων*, p. 100.

A specimen of this last variety, analysed by Mr Klaproth, was found to contain in 100 parts,

98.5 alumina

1.0 oxide of iron

0.5 lime

---

100.0 \*

Genus I. A.  
Species I.

Composition.

The colouring matter of all these varieties is, according to Bergman's experiments, iron, in different states of oxidation. He found that the topaz contained .06, the ruby .1, and the sapphire .02 of that metal †. But when these experiments were made, the analysis of stones had not arrived at a sufficient degree of perfection to ensure accuracy. No conclusion, therefore, can be drawn from these experiments, even though we were certain that they were made upon the real varieties of the sapphire.

### Sp. 2. Corundum †.

*Corundum* of Gmelin—*Adamantine spar* of Klaproth and Kirwan—*Corindon* of Haüy—*Corindum* of Woodward.

This stone, though it appears to have been known to Mr Woodward, may be said to have been first distinguished from other minerals by Dr Black. In 1768, Mr Berry, a lapidary in Edinburgh, received a box of it from Dr Anderson of Madras. Dr Black ascertained that these specimens differed from all the stones

History.

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\* Beitrage, i. 81. † Bergman, ii. 96.

† See Kirwan's *Min.* i.—Klaproth in *Beob. der Berlin*, viii. 295. and Beitrage, i. 47.—Mr Greville and the Count de Bournon in the *Philosophical Transactions* 1798, p. 403. and in Nicholson's *Jour.* ii. 540. and iii. 5. —Mr Haüy, *Jour. de Phys.* xxx. 193. and *Jour. de Min.* No. xxviii. 262.



Class I.  
Order I.

known to Europeans; and, in consequence of its hardness, it obtained the name of *adamantine spar*. Notwithstanding this, it could scarcely be said to have been known to European mineralogists till Mr Greville of London, who has done so much to promote the science of mineralogy, obtained specimens of it, in 1784, from India, and distributed them among the most eminent chemists, in order to be analysed. Mr Greville also learned that its Indian name was *Corundum*. It is found in Indostan, not far from the river Cavery, which is south from Madras, in a rocky matrix, of considerable hardness, partaking of the nature of the stone itself\*. It occurs also in China; and a substance, not unlike the matrix of corundum, has been found in Terree, one of the western islands of Scotland†.

Crystals.

The corundum is usually crystallized. Its primitive form, discovered by Mr Haüy‡ and the Count de Bournon§, is a rhomboidal parallelepiped, whose sides are equal rhombs, with angles of  $86^{\circ}$  and  $94^{\circ}$ , according to Bournon, or whose diagonals are to each other as  $\sqrt{17}$  to  $\sqrt{15}$ , according to Haüy; which is very nearly the same thing. The most common variety (for the primitive form has never yet been found) is the regular six-sided prism, the alternate angles of which are sometimes wanting, and the triangular faces, which occupy their place, are inclined to the base at an angle of  $122^{\circ} 34'$ ||. Sometimes the corundum is crystallized in the form of a six-sided pyramid, the apex of which is generally wanting. For a description and figure of these,

\* Garrow and Greville, *Nicholson's Jour.* ii. 540.

† Greville, *Ibid.*

‡ *Jour. de Min.* No. xxviii. 262.

§ *Nicholson's Jour.* ii. 541.

|| De Bournon.

and all the other varieties of corundum hitherto observed, the reader is referred to the dissertation of the Count de Bournon on the subject\*.

Genus I. A.  
Species II.

The texture of the corundum is foliated, and the natural joints are parallel to the faces of the primitive rhomboidal parallelepiped. Lustre, when in the direction of the laminae, 3; when broken across, 0. Opaque, except when in very thin pieces. Hardness 15. Specific gravity from 3.710 to 4.180†. Colour grey, often with various shades of blue and green.

Properties.

According to the analysis of Klaproth, the corundum of India is composed of 89.5 alumina

Composition.

5.5 silica  
1.25 oxide of iron  
96.25 †

A specimen from China of 84.0 alumina

6.5 silica  
7.5 oxide of iron  
98.0 §

Notwithstanding the quantity of silica and of iron which these analyses exhibit in the corundum, I have been induced to include it in the present genus, on account of the strong resemblance between it and the third variety of the sapphire. The resemblance between the crystals of these minerals appears evident even from the short description given above: and the observations of Bournon || render this resemblance

\* See also Haüy, *Four. de Min.* No. xxviii. 262.

† Klaproth. See also Greville, Nicholson's *Four.* iii. 11.

‡ Beitrage, i. 77. § Ibid. i. 73. || Nicholson's *Four.* iii. 9.

Class I.  
Order I.

still more striking. It is not improbable, therefore, as Mr Greville and the Count de Bournon have suggested, that corundum may be only a variety of the sapphire; and that the seeming difference in their ingredients is owing to the impurity of those specimens of corundum which have hitherto been brought to Europe. Let not the difference which has been found in the primitive form of these stones be considered as an insuperable objection till the subject has been again examined with this precise object in view; for nothing is easier than to commit an oversight in such difficult examinations.

*Sp. 3.* Native alumina\*.

This substance has been found at Halles in Saxony in compact kidney-form masses. Its consistence is earthy. Lustre o. Opaque. Hardness 4. Brittle. Specific gravity moderate. Feels soft, but meagre. Adheres very slightly to the tongue. Stains very slightly. Colour pure white. Does not readily diffuse itself in water.

It consists of pure alumina mixed with a small quantity of carbonat of lime, and sometimes of sulphat of lime†.

GENUS II. S.

*Sp. 1.* Quartz ‡.

Crystals.

This stone, which is very common in most mountainous countries, is sometimes crystallized, and sometimes amorphous. The primitive form of its crystals, according to Mr Haüy, is a rhomboidal parallelopiped; the

\* See Kirwan's *Min.* i. 175, and Schreber, 15 Stuck, p. 209.

† Schreber. ‡ Kirwan's *Min.* i. 241.

Genus II. S.  
Species L

angles of whose rhombs are  $93^{\circ} 22'$  and  $86^{\circ} 38'$ ; so that it does not differ much from a cube \*. The most common variety is a dodecahedron, composed of two six-sided pyramids, applied base to base, whose sides are isosceles triangles, having the angle at the vertex  $40^{\circ}$ , and each of the angles at the base  $70^{\circ}$ ; the inclination of a side of one pyramid to the contiguous side of the other pyramid is  $104^{\circ}$ . There is often a six-sided prism interposed between the two pyramids, the sides of which always correspond with those of the pyramids §. For a description and figure of the other varieties of quartz crystals, and for a demonstration of the law which they have followed in crystallizing, we refer the reader to *Rom<sup>e</sup> de Lisle* § and *Mr Hauy* ||.

The texture of quartz is more or less foliated. Fracture, conchoidal or splintery. Its lustre varies from 3 to 1, and its transparency from 4 to 1; and in some cases it is opaque. It causes a double refraction. Hardness, from 10 to 11. Specific gravity from 2.64 to 2.67, and in one variety 2.691. Its colour is exceedingly various; a circumstance which has induced mineralogists to divide it into numerous varieties. Of these the following are the chief:

1. Pure colourless, perfectly transparent crystallized quartz, having much the appearance of artificial crystal; known by the name of *rock crystal*. Varieties.
2. Quartz less transparent, and with a splintery fracture, has usually been distinguished by the name of *quartz*, and separated from rock crystal. As there is no occasion for this separation, I have, in imitation of

\* *Jour. de Min.* No. xxviii. 255. § *Crystal.* ii. 71.

|| *Mem. Par.* 1786. p. 78. See also Lametherie, *Jour. de Phys.* xlii. 470.



Class I.  
Order I.

Mr Haüy, chosen the word quartz for the *specific name*, comprehending under it all the varieties.

3. Blood red quartz; formerly called *compostella hyacinth*, and by Haüy *quartz hematoides*. It owes its colour to oxide of iron. The mineral known to mineralogists by the name of *sinople*, and considered by them as a variety of *jasper*, has been discovered by Dolomieu to be merely this variety of quartz in an amorphous state\*.

4. Yellow quartz; called false topaz.

5. Rosy red quartz; called Bohemian ruby.

For a fuller enumeration of these varieties, the reader is referred to *Smeisser's Mineralogy*† *Kirwan's Mineralogy*‡, and Gmelin's edition of the *Systema Naturæ* of Linnæus§. This last writer, however, has arranged several minerals under quartz which do not belong to it.

Pure quartz is composed entirely of silica; but some of the varieties of this species are contaminated with metallic oxides, and with a small quantity of other earths.

#### Sp. 2. Elastic Quartz ||.

This singular stone is moderately elastic, and flexible in every direction. Texture, earthy. Lustre, 0 or 1. Hardness, 9. Brittle. Specific gravity 2.624. Colour, greyish white. Phosphoresces when scraped with a knife in the dark. The specimen analysed by Mr Klaproth contained . . . 96.5 silica,

2.5 alumina,

5 oxide of iron,

---

99.5 ¶

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\* *Jour. de Min.* No. xxviii. 255. † i. 89. ‡ i. 244. § iii. 194.

¶ *Kirwan's Min.* i. 316.—*Gerhard Mem. Berlin*, 1783. p. 107.—*Klaproth's Beitrage* 2 Band. 113. See also *Jour. de Phys.* xli. 91.

¶ *Beitrage*, ii. 116.



## Sp. 3. Flint\*.

Genus II. S.  
Species III.*Pyromachus—Pierre a fusil—Silex of Hauy.*

Situation.

This stone, which has become so necessary in modern war, is found in pieces of different sizes, and usually of a figure more or less globular, commonly among chalk, and often arranged in some kind of order. In Saxony it is said to have been found crystallized in hexahedrons, composed of two low three-sided pyramids applied base to base †.

Properties.

Its texture is compact. Its fracture, smooth conchoidal. Lustre, external o, the stones being always covered by a white crust; internal r, inclining to greasy. Transparency, 2; when very thin, 3. Hardness, 10 or 11. Specific gravity, from 2.58 to 2.63. Colour varies from honey yellow to brownish black. Very brittle and splits into splinters in every direction. Two pieces of flint rubbed smartly together phosphoresce, and emit a peculiar odour. When heated it decrepitates, and becomes white and opaque. When exposed long to the air it often becomes covered with a white crust. A specimen of flint analysed by Klaproth contained . . . 98.00 silica, . . . .50 lime, . . . .25 alumina, . . . .0.25 oxide of iron, . . . .1.00 water.

Composition.

100.00 †

\* Kirwan's *Min.* i. 301.—Dolomieu, *Jour. de Min.* No. xxxiii. 693. and Salivet, *ibid.* 713. These last gentlemen give the only accurate account of the method of making gun flints.

† Gmelin's *Systema Naturæ*, iii. 183. † *Beitrag*, i. 46.

Class I.  
Order I.

Another specimen analysed by Dolomieu was composed of 97 silica,  
1 alumina and oxide of iron,  
2 water.

100 \*

The white crust with which flint is enveloped consists of the same ingredients, and also a little carbonate of lime. Dolomieu discovered that water is essential to flint; for when it is separated by heat the stone loses its properties †.

Gun flints.

The manufacture of gun flints is chiefly confined to England and two or three departments in France. The operation is exceedingly simple: a good workman will make 1000 flints in a day. The whole art consists in striking the stone repeatedly with a kind of mallet, and bringing off at each stroke a splinter, sharp at one end and thicker at the other. These splinters are afterwards shaped at pleasure, by laying the line at which it is wished they should break, upon a sharp iron instrument, and then giving it repeatedly small blows with a mallet. During the whole operation the workman holds the stone in his hand, or merely supports it on his knee ‡.

Sp. 4. Opal ||.

Situation.

This stone is found in many parts of Europe, especially in Hungary, in the Crapacks near the village of Czennizka. When first dug out of the earth it is soft, but it hardens and diminishes in bulk by exposure to the air. The substance in which it is found is a ferruginous sand-stone §.

\* *Jour. de Min.* No. xxxiii. 702.

† *Ibid.*

‡ *Ibid.*

§ *Delius, Jour. de Phys.* xlv. 45.

|| *Kirwan's Min.* i. 289.—*Haüy, Jour. de Hist. Nat.* ii. 9.—*Delius, Jour. de Phys.* xlv. 45.

The opal is usually amorphous. Its fracture is conchoidal, commonly somewhat transparent. Hardness from 6 to 10. Specific gravity from 1.7 to 2.66. The lowness of its specific gravity, in some cases, is to be ascribed to accidental cavities which the stone contains. These are sometimes filled with drops of water. Some specimens of opal have the property of emitting various coloured rays, with a particular effulgency, when placed between the eye and the light. The opals which possess this property are distinguished by lapidaries by the epithet *oriental*; and often by mineralogists by the epithet *nobilis*. This property rendered the stone much esteemed by the ancients. Opals acquire it by exposure to the sun.

Genus II. S.  
Species IV.  
Properties.

*Variety 1. Oriental or noble.*—Lustre glassy, 3. Transparency, 3 to 2. Hardness, 6 to 8. Colour, usually light bluish white, sometimes yellow or green. When heated it becomes opaque, and sometimes is decomposed by the action of the atmosphere. Hence it seems to follow that water enters essentially into its composition. A specimen of this variety, analysed by Klaproth, contained

90 silica,  
10 water.

---

100 \*

*Variety 2. Semi-opal.*—Fracture, imperfectly conchoidal. Lustre, glassy 2. Transparency 2 to 3. Hardness, 7 to 9. Its colours are very various; greys, yellows, reds, browns, greens of different kinds.

Specimens of this variety sometimes occur with rifts: these readily imbibe water, and therefore adhere to the tongue. Some opals gradually become opaque, but re-

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\* Beitrage, ii. 153.

Class I.  
Order I.

cover their transparency when soaked in water by imbibing that fluid. They are then called *hydrophanes*, or *oculi mundi*.

*Variety 3.* Cat's eye\*.—This variety comes from Ceylon, and is seldom seen by European mineralogists till it has been polished by the lapidary. Mr Klaproth has described a specimen which he received in its natural state from Mr Greville of London. Its figure was nearly square, with sharp edges, a rough surface, and a good deal of brilliancy.

Its texture is imperfectly foliated. Lustre greasy, 2. Transparency 3 to 2. Hardness 10. Specific gravity 2.56 to 2.66. Colour grey; with a tinge of green, yellow, or white: or brown, with a tinge of yellow or red. In certain positions it reflects a splendid white, as does the eye of a cat; hence the name of this stone.

Two specimens, analysed by Klaproth, the first from Ceylon, the other from Malabar, were composed of

95.00	94.50 silica
1.75	2.00 alumina
1.50	1.50 lime
0.25	0.25 oxide of iron
<hr/> 98.5†	<hr/> 98.25‡

*Sp. 5.* Pitchstone§.

*Menelites.*

Situation.

This stone, which occurs in different parts of Germany, France, and other countries, has obtained its name from some resemblance which it has been supposed to have to pitch. It is most usually in amorphous pieces of different sizes; and it has been found also cry-

\* Kirwan's *Min.* i. 301.—Klaproth, *Beitrag*, i. 90. † *Beitrag*, i. 94.

‡ *Ibid.* p. 96. § Kir. *Min.* i. 292.—Daubenton, *Mém. Par.* 1787, p. 86.

stallized in six-sided prisms, terminated by three-sided pyramids.

Genus II. S.  
Species V.

Its fracture is conchoidal and uneven, and sometimes approaches the splintery. Lustre greasy, from 3 to 1. Transparency 2 to 1, sometimes 0. Hardness 8 to 10. Exceedingly brittle; it yields even to the nail of the finger. Specific gravity 2.049 to 2.39. Its colours are numerous, greyish black, bluish grey, green, red, yellow of different shades. Sometimes several of these colours appear together in the same stone. A specimen of pitch-stone from Mesnil-montant near Paris \*, analysed by Mr Klaproth, contained

Properties.

85.5 silica  
11.0 air and water  
1.0 alumina  
.5 iron  
.5 lime and magnesia

Composi-  
tion.

98.5†

*Sp.* 6. Chrysoprasium‡.

This mineral, which is found in different parts of Germany, particularly near Kosemütz in Silesia, is always amorphous. Its fracture is either even or inclining to the splintery. Scarcely any lustre. Transparency 2 to 3. Hardness 10 to 12. Specific gravity 2.479. Colour green. In a heat of 130° Wedgewood it whitens and becomes opaque.

A specimen of this stone, analysed by Mr Klaproth, contained

\* See *Jour. de Phys.* xxxi. 219.

† *Beitrage*, ii. 169.

‡ Kirwan's *Min.* i.—Lehmann, *Mem. Berlin*, 1755, p. 202.—Klaproth, *Beitrage*, ii. 127.



Class I.  
Order I.

96.16 silica  
1.00 oxide of nickel  
0.83 lime  
0.08 alumina,  
0.08 oxide of iron  
—  
98.15\*

### GENUS. III. L.

#### Sp. I. Native Lime.

The existence of pure uncombined lime in a native state has been questioned; but the evidence on which the belief of its existence is founded is sufficiently respectable to put the matter beyond doubt. Monnet affirms that it exists in abundance in the mountains of Upper Auvergne, mixed, however, with a little oxide of iron†. Dr Falconer of Bath found a soft whitish mineral in the neighbourhood of that town, consisting partly of pure lime capable of dissolving sulphur‡, and from which lime-water may be made. I have been informed by his son Mr Thomas Falconer, that a gentleman who is at present collecting the minerals about Bath has found it, though not in any great quantity.

### GENUS IV. AMC.

#### Sp. I. Ruby§.

*Spinel* and *balass Ruby* of Kirwan—*Ruby* of Haüy  
—*Rubis spinelle octoedre* of De Lisle—*Spinellus* of Gmelin.

This stone, which comes from the island of Ceylon,

\* Beitrage, ii. 133.

† Monnet's *Mineralogy*, p. 515.

‡ *On Bath Waters*, p. 156.

§ See Kirwan's *Min.* i. 253.—Romé de Lisle, ii. 224.—Klaproth *Beob. der Berlin*, iii. 336. and Beitrage, ii. 1.—Vauquelin *Ann. de Chim.* xxvii. 3. and xxxi. 141.

is usually crystallized. The form of its integrant particles is the tetrahedron. The primitive form of its crystals is a regular octahedron, composed of two four-sided pyramids applied base to base, each of the sides of which is an equilateral triangle \*. In some cases two opposite sides of the pyramids are broader than the other two; and sometimes the edges of the octahedron are wanting, and narrow faces in their place. For figures and descriptions of these, and other varieties of these crystals, the reader is referred to *Romé de Lisle* and the *Abbé Estner* †.

Genus IV.  
Amc.  
Species I.  
Crystals.

The texture of the ruby is foliated. Its lustre is 3. Transparency 3 to 4. It causes a single refraction. Hardness 13. Specific gravity 3.570‡ to 3.625 §. Colour red; if deep, the ruby is usually called *balass*; if pale rosy, *spinell*.

Properties.

The ruby, according to the analysis of Vauquelin, is composed of

86.00	alumina,
8.50	magnesia,
5.25	chromic acid.

Composition.

99.75 ||

The ancients seem to have classed this stone among their hyacinths ¶.

# GENUS V. AIM.

## Sp. I. Ceylanite.

The mineral denominated *ceylanite*, from the island of Ceylon, from which it was brought into Europe, had

History.

\* This octahedron is usually distinguished either by the epithet *regular* or *aluminiform*, because it is the well-known form of crystals of alum.

† *Crystall.* ii. 226.—*Estner's Miner.* 73.

‡ Klaproth.

§ Hatchette and Greville.

|| *Ann. de Chim.* xxvii. 15.

¶ *Plinii*, lib. xxxvii. c. 9.

Class I. Order I.	been observed by Romé de Lisle *; but was first described by La Metherie in the <i>Journal de Physique</i> for January 1793.										
Crystals.	It is most commonly found in rounded masses; but sometimes also crystallized. The primitive form of its crystals is a regular octahedron: it commonly occurs under this form, but more commonly the edges of the octahedron are wanting, and small faces in their place †.										
Properties.	The fracture of the ceylanite is conchoidal ‡. Its internal lustre is glassy. Nearly opaque, except when in very thin pieces. Hardness 12. Specific gravity from 3.7647 § to 3.793   . Colour of the mass, black; of very thin pieces, deep green. Powder, greenish grey.										
Composition.	According to the analysis of Descotils the ceylanite is composed of, <table> <tr> <td>68</td><td>alumina,</td></tr> <tr> <td>16</td><td>oxide of iron,</td></tr> <tr> <td>12</td><td>magnesia,</td></tr> <tr> <td>2</td><td>silica.</td></tr> <tr> <td>98</td><td>¶</td></tr> </table>	68	alumina,	16	oxide of iron,	12	magnesia,	2	silica.	98	¶
68	alumina,										
16	oxide of iron,										
12	magnesia,										
2	silica.										
98	¶										

## GENUS VI. I. As.

*Sp. 1. Topaz \*\*.**Occidental ruby, topaz, and sapphire.*

## History.

The name *topaz* has been restricted by Mr Haüy to the stones called by mineralogists occidental ruby, topaz, and sapphire; which, agreeing in their crystallization and most of their properties, were arranged under one species by Mr Romé de Lisle. The word *topaz*, deri-

\* *Cryst illog.* iii. 180. Note 21. † Haüy, *Jour. de Min.* No. xxxviii. 264.

† Ibid. 263. § Haüy. || Descotils. ¶ *Ann. de Chim.* xxxiii. 113.

\*\* Kirwan's *Min.* i. 254.—Pott. *Mem. Berlin*, 1747, p. 46.—Margraf, *ibid.* 1776. p. 73. and 160.—Henkel, *Act. Acad. Nat. Cur.* iv. 316.

ved from an island in the Red Sea\*, where the ancients used to find topazes, was applied by them to a mineral very different from ours. One variety of our topaz they denominated *chrysolite*.

Genus VI.  
As.  
Species I.

The topaz is found in Saxony, Bohemia, Siberia, and Brazil, mixed with other minerals in granite rocks.

It is commonly crystallized. The primitive form of its crystals is a prism whose sides are rectangles and bases rhombs, having their greatest angles  $124^{\circ} 22'$  and the integral molecule has the same form †; and the height of the prism is to a side of the rhomboidal bases as 3 to 2. The different varieties of topaz crystals hitherto observed amount to 6. Five of these are eight-sided prisms, terminated by four-sided pyramids, or wedge-shaped summits, or by irregular figures of 7, 13, or 15 sides; the last variety is a twelve-sided prism, terminated by six-sided pyramids wanting the apex. For an accurate description and figure of these varieties the reader is referred to Mr Haüy ‡.

Crystals.

The texture of the topaz is foliated. Its lustre is from 2 to 4. Transparency from 2 to 4. It causes a double refraction. Hardness 12 to 14. Specific gravity from 3.5311 to 3.564. The Siberian and Brazil topazes, when heated, become positively electrified on one side, and negatively on the other§. It is infusible by the blow-pipe. The yellow topaz of Brazil becomes red when exposed to a strong heat in a crucible; that of Saxony becomes white by the same process.

Properties.

\* It got its name from *τοπαζω*; to seek; because the island was often surrounded with fog, and therefore difficult to find. See Plinii, lib. xxxvii. c. 8.

† Haüy, *Jour. de Min.* No. xxviii. 287.

‡ *Jour. de Min.* ibid.

§ Haüy, ibid.

Class I.  
Order I.

This shews us that the colouring matter of these two stones is different.

The colour of the topaz is various, which has induced mineralogists to divide it into the following varieties:

Varieties.

1. Red topaz, of a red colour, inclining to yellow; called *Brazilian* or *occidental ruby*.

2. Yellow topaz, of a golden yellow colour, and sometimes also nearly white; called *occidental* or *Brazil topaz*. The powder of this and the following variety causes syrup of violets to assume a green colour\*.

3. Saxon topaz. It is of a pale wine yellow colour, and sometimes greyish white.

4. Aigue marine. It is of a bluish or pale green colour.

5. Occidental sapphire. It is of a blue colour; and sometimes white.

A specimen of white Saxon topaz, analysed by Vauquelin, contained

68 alumina

31 silica

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99†

*Sp. 2. Sommite.*

*Hexagonal white shorl* of Verber—*White hyacinth* of Somma.

This stone was called *sommite* by Lametherie, from the mountain Somma, where it was first found. It is usually mixed with volcanic productions. It crystallizes in six-sided prisms, sometimes terminated by pyramids. Colour white. Somewhat transparent. Cuts glass. Specific gravity 3.2741. Infusible by the blow-

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\* Vauquelin, *Jour. de Min.* No. xxix. 165.    † Ibid. No. xxiv. 3.



pipe. According to the analysis of Vauquelin, it is		Genus VI.
composed of	49 alumina	As.
	46 silica	Species III.
	2 lime	
	1 oxide of iron	
	<hr/> 98*	

*Sp. 3. Shorlite†.*

This stone, which received its name from Mr Klaproth, is generally found in irregular oblong masses or columns, inserted in granite. Its texture is foliated. Fracture uneven. Lustre 2. Transparency 2 to 1. Hardness 9 to 10. Specific gravity 3.53. Colour greenish white, or sulphur yellow. Not altered by heat. According to the analysis of Klaproth, it is composed of

50 alumina
50 silica

---

100

## GENUS VI. 2. SA.

*Sp. 4. Rubellite †.—Siberite of Lermine.*

*Red shorl of Siberia—Daourite of Delametherie.*

This stone is found in Siberia mixed with white quartz. It is crystallized in small needles, which are grouped together, and traverse the quartz in various directions. Texture fibrous. Fracture glassy, inclining to the conchoidal. Transparency 2; at the edges 3. Hardness 10. Brittle. Specific gravity 3.048. Colour crimson, blood, or peach red. By exposure to a red heat it becomes snow white; but loses none of its

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\* *Jour. de Min.* No. xxviii. 279.

† Kirwan's *Min.* i. 286.

† Kirwan's *Min.* i. 288.—Bindheim, Crell's *Annals*, 1792, p. 320.—Lermine, *Jour. de Phys.* xlix. 374.

Class I.  
Order I.

weight. It tinges soda blue, but does not melt with it. When heated, acquires the electricity of the tourmaline.

According to the analysis of Mr Bindheim, it is composed of . . . . .

57	silica
35	alumina
5	oxides of iron and manganese
97	

According to Lermina of

36	silica
48	alumina
3 $\frac{1}{2}$	lime
9	oxide of manganese
96 $\frac{1}{2}$	

*Sp. 5. Hornslate\*.*

*Shistose porphyry.*

This stone, which occurs in mountains, is generally amorphous; but sometimes also in columns. Structure slaty. Texture foliated. Fracture uneven and splintery; sometimes approaching the conchoidal. Lustre o. Transparency 1 or o. Hardness about 10. Specific gravity from 2.512 to 2.7. Colour different shades of grey, from ash to bluish or olive green. Melts at 145° Wedgewood into an enamel. A specimen analysed by Wedgewood contained

73.0	silica
23.9	alumina
3.5	iron
100.4	

*Sp. 6. Hornstone†.*

*Petrosilex—Chert.*

This stone, which makes a part of many mountains,

\* Kirwan's *Min.* i. 307.—Wiegleb, *Crell's Annals*, 1787, 1 Band. 302. See also Reuss, *Samml. Natur. Hist. Aufsätze*, p. 207.

† Kirwan's *Min.* i. 303.—Baumer, *Jour. de Phys.* ii. 154. and Monnet, *Ibid.* 331.—Wiegleb, *Crell's Annals*, 1788, p. 45. and 135.—*Jour. de Phys.* lii. 239.

is usually amorphous ; but, as Mr Kirwan informs us, it has been found crystallized by Mr Beyer on Schneeberg. Its crystals are six-sided prisms, sometimes terminated by pyramids ; hexahedrons, consisting of two three-sided pyramids applied base to base ; and cubes, or six-sided plates \*. Its texture is foliated. Fracture splintery, and sometimes conchoidal. Lustre o. Transparency 1 to 2. The crystals are sometimes opaque. Hardness 7 to 9. Specific gravity 2.532 to 2.653. Colour usually dark blue : but hornstone occurs also of the following colours ; grey, red, blue, green, and brown of different shades †.

Genus VI.  
2. 8A.  
Species VII.

Properties.

According to Kirwan, it is composed of

72 silica
22 alumina
6 carbonat of lime
100 †

Composition.

*Sp. 7. Chalcedony.*

This stone is found abundantly in many countries, particularly in Iceland and the Faro islands. It is most commonly amorphous, stalactitical, or in rounded masses ; but it occurs also crystallized in six-sided prisms, terminated by pyramids, or more commonly in four or six-sided pyramids, whose sides are convex. Surface rough. Fracture more or less conchoidal. Lustre 1. Somewhat transparent. Hardness 10 to 11. Specific gravity 2.56 to 2.665. Not brittle.

According to Bergman, the chalcedony of Faro is composed of . . . 84 silica

16 alumina, mixed with iron
100

\* Kirwan's *Min.* i. 303.

† Schmeisser's *Min.* i. 103.

‡ Ibid. p. 305.

Class I.  
Order I.  
Varieties.

*Variety 1.* Common chalcedony.—Fracture even, inclining to conchoidal. Transparency 2 to 3; sometimes 1. Its colours are various; it is most commonly greyish, with a tint of yellow, green, blue, or pearl; often also white, green, red, yellow, brown, black, or dotted with red. When striped white and black, or brown, alternately, it is called *onyx*; when striped white and grey, it is called *chalcedonix*. Black or brown chalcedony, when held between the eye and a strong light, appears dark red.

*Variety 2.* Cornelian.—Fracture conchoidal. Transparency 3 to 1; often cloudy. Its colours are various shades of red, brown, and yellow. Several colours often appear in the same mass. To this variety belong many of the stones known by the name of *Scotch pebbles*.

*Sp. 8.* Jasper\*.

This stone is an ingredient in the composition of many mountains. It occurs usually in large amorphous masses, and sometimes also crystallized in six-sided irregular prisms. Its fracture is conchoidal. Lustre from 2 to 0. Either opaque, or its transparency is 1. Hardness 9 to 10. Specific gravity from 2.5 to 2.82. Its colours are various. When heated, it does not decrepitate. It seems to be composed of silica and alumina, and often also contains iron.

Varieties.

*Variety 1.* Common jasper.—Specific gravity from 2.58 to 2.7. Its colours are, different shades of white, yellow, red, brown, and green; often variegated, spotted, or veined, with several colours.

*Variety 2.* Egyptian pebble.—This variety is found

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\* Kirwan's *Min.* i. 309.—Borral, *Hist. Natur. de Corse*.—Henkel, *Act. Acad. Nat. Curios.* v. 339.

chiefly in Egypt. It usually has a spheroidal or flat rounded figure, and is enveloped in a coarse rough crust. It is opaque. Hardness 10. Specific gravity 2.564. It is chiefly distinguished by the variety of colours, which always exist in the same specimen, either in concentric stripes or layers, or in dots or dendritical figures. These colours are, different browns and yellows, milk white, and isabella green; black also has been observed in dots.

*Variety 3.* Striped jasper.—This variety is also distinguished by concentric stripes or layers of different colours: these colours are, yellow, brownish red, and green. It is distinguished from the last variety by its occurring in large amorphous masses, and by its fracture, which is nearly even.

*Sp. 9.* Tripoli.

This mineral is found sometimes in an earthy form, but more generally indurated. Its texture is earthy. Its fracture often somewhat conchoidal. Lustre 0. Generally opaque. Hardness 4 to 7. Specific gravity 2.680 to 2.529. Absorbs water. Feel, harsh dry. Hardly adheres to the tongue. Takes no polish from the nail. Does not stain the fingers. Colour generally pale yellowish grey, also different kinds of yellow, brown, and white.

It contains, according to Haasse, 90 parts of silica, 7 alumina, and 3 of iron. A mineral belonging to this species was analysed by Klaproth, and found to contain

66.5	silica
7.0	alumina
2.5	oxide of iron
1.5	magnesia
1.25	lime
19.0	air and water
97.75	

Genus VI.  
2. SA.  
Species IX.

Properties.

Composition.



Class I.  
Order I.

## GENUS VII. I. ASI.

## Sp. 1. Micarell\*.

This name has been given by Mr Kirwan to a stone which former mineralogists considered as a variety of mica. It is found in granite. Its texture is foliated, and it may be split into thin plates. Lustre metallic, 3. Opaque. Hardness 6. Specific gravity, 2.980. Colour brownish black. At 153° Wedgewood, it melts into a black compact glass, the surface of which is reddish†.

Composi-  
tion.

A specimen analysed by Klaproth contained

63.00 alumina

29.50 silica

6.75 iron

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99.25

## Sp. 2. Shorl†.

**History.** No word has been used by mineralogists with less limitation than *shorl*. It was first introduced into mineralogy by Cronstedt, to denote any stone of a columnar form, considerable hardness, and a specific gravity from 3 to 3.4. This description applied to a very great number of stones; and succeeding mineralogists, though they made the word more definite in its signification, left it still so general, that under the designation of *shorl* almost 20 distinct species of minerals were included.

Mr Werner first defined the word *shorl* precisely, and restricted it to one species of stones. I use the word in the sense assigned by him.

Shorl is found abundantly in mountains, either massive, or crystallized in three or nine sided prisms, often

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\* Kirwan's *Min.* i. 212.

† Kirwan, *Ibid.*

‡ *Ibid.* i. 265.

terminated by three-sided summits. The sides of the crystals are longitudinally streaked. Its texture is foliated. Its fracture conchoidal. Lustre 2. Opaque. Hardness 10. Specific gravity 2.92 to 3.212. Colour black. Streak grey. It does not become electric by heat. When heated to redness, its colour becomes brownish red; and at 127° Wedgewood, it is converted into a brownish compact enamel\*. According to Wiegleb, it is composed of

Genus VII.  
I. ASI.  
Species III.  
Properties.

41.25 alumina  
34.16 silica  
20.00 iron  
5.41 manganese

Composition.

100.82†

Sp. 3. Granatite.

*Staurotide* of Haüy—*Pierre de Croix* of De Lisle—*Staurolithe* of Lametherie.

I have adopted from Mr Vauquelin the term *granatite* to denote this stone, because all the other names are ambiguous, having been applied to another mineral possessed of very different properties.

Granatite is found in Galicia in Spain, and Brittany in France. It is always crystallized in a very peculiar form; two six-sided prisms intersect each other, either at right angles or obliquely. Hence the name *cross-stone*, by which it was known in France and Spain‡. Mr Haüy has proved, in a very ingenious manner, that the primitive form of the granatite is a rectangular prism, whose bases are rhombs, with angles of  $129\frac{1}{2}^\circ$  and  $50\frac{1}{2}^\circ$ ; and that the height of the prism is to the

Crystals.

\* Kirwan's *Min.* i. 166.

† Crell's *Beitrag*, i. Band. 4 Stuck., p. 21. ‡ Romé de Lisle, ii. 435.

Class I.  
Order I.

greater diagonal of a rhomb as 1 to 6; and that its integrant molecules are triangular prisms, similar to what would be obtained by cutting the primitive crystal in two, by a plane passing vertically through the shorter diagonal of the rhomboidal base. From this structure he has demonstrated the law of the formation of the cruciform varieties\*. The colour of granatite is greyish or reddish brown. Specific gravity 3.2861. Hardness 12. Texture compact. Usually opaque,

Composition.

According to the analysis of Vauquelin, it is composed of

47.06 alumina  
30 59 silica  
15.30 oxide of iron  
3.00 lime

95.95†

#### GENUS VII. 2. SAI.

##### *Sp.* 4. Tourmaline †.

This stone was first made known in Europe by specimens brought from Ceylon; but it is now found frequently forming a part of the composition of mountains. It is either in amorphous pieces, or crystallized in three or nine sided prisms, with four-sided summits. The primitive form of its crystals is an obtuse rhomboid; that of its integrant particles an irregular tetrahedron.

Its texture is foliated: Its fracture conchoidal. Internal lustre 2 to 3. Transparency 3 to 4; sometimes

\* *Ann. de Chim.* vi. 142.

† *Ibid.* xxx. 106.

‡ Kirwan, i. 271.—Bergman, ii. 118. and v. 402.—Gerhard, *Mém. Berl.* 1777, p. 14.—Haüy, *Mém. Par.* 1784, p. 270.—Wilson, *Phil. Trans.* xli. 308.—Æpinus, *Recueil sur la Tourmaline*.—See also La Porterie, *le Sapphir, l'Oeil de Chat, et la Tourmaline de Ceylon démasqués*.

only 2\*. Causes only single refraction†. Hardness 9 to 11. Specific gravity 3.05 to 3.155. Colour brown, often so dark that the stone appears black; the brown has also sometimes a tint of green, blue, red, or yellow.

Genus VII.  
2. S.A.L.  
Species V.

When heated to 200° Fahrenheit, it becomes electric; one of the summits of the crystal negatively, the other positively‡. It reddens when heated; and is fusible *per se* with intumescence into a white or grey enamel.

A specimen of the tourmaline of Ceylon, analysed by Vauquelin, was composed of

Composi-  
tion.

40	silica
39	alumina
12	oxide of iron
4	lime
2.5	oxide of manganese

---

97.5 §

*Sp. 5. Argentine felspar* ||.

This stone was discovered by Mr Dodun in the black mountains of Languedoc. It is either amorphous, or crystallized in rhomboidal tables, or six or eight sided prisms. Its texture is foliated. Fragments rectangular. Laminæ inflexible. Internal lustre 4. Transparency 2. Colour white; two opposite faces of the crystals are silver white, two others dead white. Hardness of the silver laminæ 6, of the rest 9. Brittle. Specific gravity 2.5. When the flame of the blow-pipe

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\* And when black only 1. It is always opaque when viewed in a direction parallel to the axis of the crystal.

† Haüy, *Four. de Min.* No. xxviii. 265.

§ *Ann. de Chim.* xxx. 105.

‡ Æpinus.

|| Kirwan, i. 327.

Class I.  
Order I.

is directed against the edges of the crystal (stuck upon glass), it easily melts into a clear compact glass; but when the flame is directed against the faces, they preserve their lustre, and the edges alone slowly melt.

According to the analysis of Dodun, it is composed

of	46 silica
	36 alumina
	16 oxide of iron
	<hr/>
	98

When this stone is exposed to the atmosphere, it is apt to decay: Its surface becomes iridescent, and at last changes to ochre-yellow: Its specific gravity is 2.3 or 2.212; and when breathed upon, it gives out an earthy smell.

*Sp. 6. Mica\*.*

This stone forms an essential part of many mountains, and has been long known under the names of *glacies marie* and *Muscovy glass*. It consists of a great number of thin laminae adhering to each other, sometimes of a very large size. Specimens have been found in Siberia nearly  $2\frac{1}{2}$  yards square †.

Crystals.

It is sometimes crystallized: Its primitive form is a rectangular prism, whose bases are rhombs, with angles of  $120^\circ$  and  $60^\circ$ : Its integrant molecule has the same form. Sometimes it occurs in rectangular prisms, whose bases also are rectangles, and sometimes also in short six-sided prisms; but it is much more frequently in plates or scales of no determinate figure or size ‡.

\* Kirwan, i. 210.—Gmelin, *Nov. Com. Petropol.* xii. 549.

† *Hist. General de Voyages*, t. xviii. 272. quoted by Haüy, *Jour. de Min.* No. xxviii. 299.

‡ Haüy, *Jour. de Min.* No. xxviii. 296.



Its texture is foliated. Its fragments flat. The lamellæ flexible, and somewhat elastic. Lustre metallic, from 3 to 4. Transparency of the laminæ 3 or 4, sometimes only 2\*. Hardness 6. Very tough. Often absorbs water. Specific gravity from 2.6546 to 2.9342. Feels smooth, but not greasy. Powder feels greasy. Colour, when purest, silver white or grey; but it occurs also yellow, greenish, reddish, brown, and black. Mica is fusible by the blow-pipe into a white, grey, green, or black enamel; and this last is attracted by the magnet†. Spanish wax rubbed by it becomes negatively electric‡.

Genus VII.  
2. SAI.  
Species VII.  
Properties.

A specimen of mica, analysed by Vauquelin, contained

50.00	silica
35.00	alumina
7.00	oxide of iron
1.35	magnesia
1.33	lime
<hr/>	
94.68	§

Composition.

Mica has long been employed as a substitute for glass. A great quantity of it is said to be used in the Russian marine for panes to the cabin windows of ships; it is preferred, because it is not so liable as glass to be broken by the agitation of the ship.

*Sp.* 7. Talc ¶.

This stone has a very strong resemblance to mica,

\* Black mica is often nearly opaque.

† Haüy, *Jour. de Min* No. xxviii. p. 295. Bergman, however, found pure mica infusible *per se*.

‡ Ibid.

§ Ibid.

¶ Kirwan, i. 150.—*Pott. Mem. Berl.* 1746, p. 65.

Class I.  
Order I.

and was long considered as a mere variety of that mineral. It occurs sometimes in small loose scales, and sometimes in an indurated form ; but it has not hitherto been found crystallized.

Properties.

Its texture is foliated. The lamellæ are flexible, but not elastic. Its lustre is from 2 to 4. Transparency from 2 to 4. Hardness 4 to 6. Specific gravity, when indurated, from 2.7 to 2.8. Feels greasy. Colour most commonly whitish or greenish. Spanish wax rubbed with it becomes *positively* electric \*.

Varieties.

*Variety 1.* Scaly talc. *Talcite* of Kirwan.—This variety occurs under the form of small scales, scarcely cohering. Lustre 3 to 4. Very light. Adheres to the fingers. When rubbed upon the skin, it gives it a gloss. Colour white, with a shade of red or green ; sometimes leek green.

*Variety 2.* Common talc. *Venetian talc*.—This variety often occurs in oblong nodules. Lustre, nearly metallic, 4. Transparency 2 to 3 ; when very thin 4. Hardness 4 to 5. Colour white, with a shade of green or red ; or apple green, verging towards silver white. By transmitted light green.

*Variety 3.* Shistose talc —Its structure is slaty. Fracture hackly and long splintery. Easily crumbles when rubbed in the fracture. External lustre, 2 to 3 ; internal, 1 ; but sometimes, in certain positions, 3. Colour grey, with a shade of white, green, or blue. Becomes white and scaly when exposed to the air.

A specimen of *common talc*, analysed by Mr Chenevix, contained

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\* Haüy, *Jour de Min.* No. xxviii. 291.

48.0	silica
37.0	alumina
6.0	oxide of iron
1.5	magnesia
1.5	lime
5.0	water
<hr/>	
99.0	*

Genus VII.  
2. SAT.  
Sp. VIII.

*Sp. 8. Basaltine†.*

*Basaltic hornblende* of Werner—*Actinote* of Haüy—  
*Zillertite* of Lametherie.

This stone is found commonly in basaltic rocks; hence its name, which was imposed by Mr Kirwan. It is crystallized, either in rhomboidal prisms, or six or eight-sided prisms, terminated by three-sided pyramids. The primitive form of its crystals is a rhomboidal prism. Its texture is foliated. Its fracture uneven. Lustre 3. Transparency, when in very thin plates, 1. Hardness from 9 to 10. Specific gravity 3.333. Colour black, dark green, or yellowish green. Streak white. Transmits a reddish yellow light. Before the blow-pipe it melts into a greyish coloured enamel, with a tint of yellow‡. A specimen, seemingly of this stone, analysed by Bergman, contained

58	silica
27	alumina
9	iron
4	lime
1	magnesia
<hr/>	
99§	

Properties.  
  
Composition.

\* *Ann. de Chim.* xxviii. 200.

† *Le Lievre, Jour. de Min.* No. xxviii. 269.

‡ Kirwan, i. 219.

§ Bergman, iii. 207.

Class I.  
Order I.

*Sp. 9. Hornblende\*.*

*Amphibole* of Haüy†.

This stone enters into the composition of various mountains. Its texture is very conspicuously foliated. Fracture conchoidal. Fragments often rhomboidal. Lustre 2. Opaque. Hardness 5 to 9. Tough. Specific gravity 2.922 to 3.41. Colour black, blackish green, olive green, or leek green. Streak greenish. It neither becomes electric by friction nor heat‡. Before the blow-pipe it melts into a black glass. A specimen of black hornblende, analysed by Mr Hermann, was composed of

Composi-  
tion.

57 silica  
27 alumina  
25 iron  
5 lime  
3 magnesia

---

97§

*Sp. 10. Resplendent Hornblende.*

There are two minerals which Werner considers as varieties of hornblende, and Mr Kirwan as constituting a distinct species. These, till future analyses decide the point, I shall place here under the name of resplendent hornblende, the name given them by Mr Kirwan; and I shall describe them separately.

Varieties.

*Variety 1. Labrador hornblende.*—Texture curved foliated. Lustre, in some positions, 0; in others metallic, and from 3 to 4. Opaque. Hardness 8 to 9.

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\* Kirwan, i. 213.

† Under this name Mr Haüy comprehends *horn* also.

‡ Haüy, *Jour. de Min.* No. xxviii. 267.

§ *Beob. der Berlin*, 5 Band. 317.

Genus VII.  
2. SAI.  
Species XI.

Specific gravity from 3.35 to 3.434. Colour, in most positions, greyish black; in others, it reflects a strong iron grey, sometimes mixed with copper red.

*Variety 2.* Shiller spar\*.—Texture foliated. Lustre metallic, 4. Transparency, in thin pieces, 1. Hardness 8 to 9. Specific gravity 2.882. Colour green, often with a shade of yellow; also golden yellow. In some positions it reflects white, grey, or yellow. At 141°. Wedgewood, hardened into a porcelain mass. A specimen, analysed by Gmelin, was composed of

43.7 silica  
17.9 alumina  
23.7 iron  
11.2 magnesia

---

96.5†

It has been found in the Hartz, stuck in a serpentine rock.

*Sp. II.* Obsidian‡.

*Iceland agate.*

This stone is found either in detached masses, or forming a part of the rocks which compose many mountains. It is usually invested with a grey or opaque crust. Its fracture is conchoidal. Its internal lustre 3. Transparency 1. Hardness 10. Specific gravity 2.348. Colour black or greyish black: when in very thin pieces, green. It melts into an opaque grey mass. According to Bergman, it is composed of

69 silica  
22 alumina  
9 iron  

---

100§

\* Kirwan, i. 221.

† Kirwan, i. 264.

‡ Bergbaukunde, i. Band. p. 92.

§ Bergman, iii. 204.



Class I.  
Order I.

*Sp. 12. Petrilite\*.*

*Cubic felspar.*

This stone is found in the mass of mountains. It is amorphous. Texture foliated. Fracture splintery. Fragments cubic, or inclining to that form; their faces unpolished. Lustre 2. Transparency partly 2, partly 1. Hardness 9. Specific gravity, 3.081. Colour reddish brown. Does not melt at 160° Wedgewood.

*Sp. 13. Felsite†.*

*Compact felspar.*

This stone also forms a part of many mountains, and is amorphous. Texture somewhat foliated. Fracture uneven, approaching to the splintery. Lustre 1. Transparency scarce 1. Hardness 9. Colour azure blue, and sometimes brown and green. Streak white. Before the blow-pipe whitens and becomes rifted; but is infusible *per se*.

#### GENUS VIII. SNAW.

*Sp. 1. Pimelite.*

The mineral distinguished by this name is an earthy substance, of an apple green colour, which accompanies the chrysopase of Tkosemütz. Klaproth has analysed it, and found it composed of the following ingredients.

35.00	silica
15.62	oxide of nickel
5.00	alumina
4.58	oxide of iron
1.25	magnesia
37.91	water
99	36†

\* Kirwan, i. 325.

† Ibid. 326.

‡ *Jour. de Phys.* lii. 39.

## GENUS IX. SAP.

Genus IX.  
SAP.  
Species I.*Sp. 1. Felspar\*.*

This stone forms the principal part of many of the highest mountains. It is commonly crystallized. Its primitive form, according to De Lisle, is a rectangular prism, whose bases are rhombs, with angles of  $65^{\circ}$  and  $115^{\circ}$ . Sometimes the edges of the prism are wanting, and faces in their place; and sometimes this is the case also with the acute angles of the rhomb. For a description and figure of these, and other varieties, the reader is referred to *Romé de Lisle* †, *Mr Hauy* ‡, and *Mr Pini* §.

Its texture is foliated. Its cross fracture uneven. Fragments rhomboidal; and commonly smooth and polished on four sides. Lustre of the polished faces often 3. Transparency from 3 to 1. Hardness 9 to 10. Specific gravity from 2.437 to 2.7. Gives a peculiar odour when rubbed. It is made electric with great difficulty by friction. Fusible *per se* into a more or less transparent glass. When crystallized, it decrepitates before the blow-pipe.

*Variety 1. Pure felspar. Moonstone—Adularia.* This is the purest felspar hitherto found. It occurs in Ceylon and Switzerland; and was first mentioned by Mr Sage. Lustre nearly 3. Transparency 2 to 3. Hardness 10. Specific gravity 2.559. Colour white; sometimes with a shade of yellow, green, or red. Its surface is sometimes iridescent.

*Variety 2. Common felspar.* Lustre of the cross

\* Kirwan, i. 316. and *Jour. de Phys.* passim.

† *Crystall.* ii. 461.

‡ *Mém. Par.* 1784, p. 273.

§ *Sur de Nouvelle Crystallisation*, &c. 8.

Class I.  
Order I.

fracture 0; of the fracture, in the direction of the laminae, from 3 to 1. Transparency 2 to 1. Colour most commonly flesh red; but often bluish grey, yellowish white, milk white, brownish yellow; and sometimes blue, olive green, and even black.

*Variety 3.* Labradorite felspar.—This variety was discovered on the coast of Labrador by Mr Wolfe; and since that time it has been found in Europe. Lustre 2 to 3. Transparency from 1 to 3. Specific gravity from 2.67 to 2.6925. Colour grey. In certain positions, spots of it reflect a blue, purple, red, or green colour.

*Variety 4.* Continuous felspar.—This variety most probably belongs to a different species; but as it has not hitherto been analysed, I did not think myself at liberty to alter its place.

It is found in large masses. Texture earthy. Fracture uneven, sometimes splintery. Lustre 0. Transparency 1. Hardness 10. Specific gravity 2.609. Colour reddish grey, reddish yellow, flesh red.

Composition,

A specimen of green felspar from Siberia, analysed by Vauquelin, contained 62.83 silica,

17.02 alumina,

16.00 potass,

3.00 lime,

1.00 oxide of iron.

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99.85 \*

*Sp. 2.* Lepidolite †.

*Lilalite.*

This stone appears to have been first observed by the

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\* *Ann. de Chim.* xxx. 106.

† Kirwan, i. 208.—Karsten, *Beob. der Berlin*, 5 Band, 71.—Klaproth's *Beitrage*, i. 279. and ii. 191.

Abbé Poda, and to have been first described by De Born \*. Hitherto it has only been found in Moravia in Germany, and Sudermania in Sweden †. There it is mixed with granite in large amorphous masses. It is composed of thin plates, easily separated, and not unlike those of mica ‡. Lustre, pearly §. Transparency between 1 and 2. Hardness 4 to 5. Not easily pulverised ¶. Specific gravity from 2.816 || to 2.8549 ¶. Colour of the mass, violet blue; of the thin plates, silvery white. Powder white, with a tint of red \*\*. Before the blow-pipe, it froths, and melts easily into a white semitransparent enamel, full of bubbles. Dissolves in borax with effervescence, and communicates no colour to it ††. Effervesces slightly with soda, and melts into a mass spotted with red. With microcosmic salt, it gives a pearl-coloured globule ‡‡.

Genus IX.  
SAP.  
Species II.

Properties.

This stone was first called lilalite from its colour, that of the *lily*. Klaproth, who discovered its component parts, gave it the name of *lepidolite* §§.

It is composed of

53	silica,
20	alumina,
18	potass,
5	fluat of lime,
3	oxide of manganese,
1	oxide of iron.

Composition.

100 |||

\* Crell's *Annals*, 1791, ii. 196.

† Beyer, *Ann. de Chim.* xxix. 108.

‡ Le Lievre, *Jour. de Min.* No. li. 219.

§ Ibid.

|| Klaproth.

¶ Hauy. \*\* Le Lievre, *Jour. de Min.* No. li. 219.

†† Ibid.

‡‡ Klaproth, *Ann. de Chim.* xxii. 37.

§§ That is, *scale stone*, or stone composed of scales: From *lapis*, the *scale of a fish*, and *lithos*, a *stone*.

||| Vauquelin, *Ann. de Chim.* xxx. 105.

Class I.  
Order I.

*Sp. 3. Leucite \*.*

*Vesuvian* of Kirwan—*White garnet* of Vesuvius.

Crystals.

This stone is usually found in volcanic productions, and is very abundant in the neighbourhood of Vesuvius. It is always crystallized. The primitive form of its crystals is either a cube or a rhomboidal dodècahedron, and its integrant molecules are tetrahedrons; but the varieties hitherto observed are all polyhedrons. The most common has a spheriodal figure, and is bounded by 24 equal and similar trapezoids; sometimes the faces are 12, 18, 36, 54, and triangular, pentagonal, &c. For a description and figure of several of these, I refer the reader to Mr Haüy †. The crystals vary from the size of a pin head to that of an inch.

Properties.

The texture of the leucite is foliated. Its fracture somewhat conchoidal. Lustre 3; when in a state of decomposition 0. Transparency 3 to 2; when decomposing 0. Hardness 8 to 10; when decomposing 5 to 6. Specific gravity 2.4648. Colour white, or greyish white ‡. Its powder causes syrup of violets to assume a green colour §.

Composition,

It is composed, as Klaproth has shewn, of

54 silica  
23 alumina  
22 potass

99 ||

It was by analysing this stone that Klaproth disco-

\* Kirwan, i. 285. . . . . † *Jour. de Min.* No. xxvii. 185.

‡ Hence the name leucite, from λευκος, *white*.

§ Vauquelin, *Jour. de Min.* No. xxxix. 165.

|| See *Jour. de Min.* No. xxvii. 194. and 201. and Klaproth's *Beitrag*, ii. 39.



vered the presence of potass in the mineral kingdom; which is not the least important of the numerous discoveries of that accurate and illustrious chemist.

Genus X.  
SAG.  
Species I.

Leucite is found sometimes in rocks which have never been exposed to volcanic fire; and Mr Dolomieu has rendered it probable, from the substances in which it is found, that the leucite of volcanoes has not been formed by volcanic fire, but that it existed previously in the rocks upon which the volcanoes have acted, and that it was thrown out unaltered in fragments of these rocks\*.

*Sp. 4. White Chlorite.*

This is a mineral composed of brilliant scales of a silvery white colour, very soft, and when rubbed upon other bodies, leaving a powder resembling the scales of fish. Smell argillaceous. Water in which it is agitated becomes alkaline. Before the blow-pipe, melts into a greenish white enamel. When calcined, loses 0.06 of its weight, and becomes reddish. It is composed of

56 silica

18 alumina

8 potass

3 lime

4 oxides of iron and manganese

6 water

95 †

GENUS X. SAG.

*Sp. I. Emerald ‡.*

This stone has hitherto been only found crystallized.

\* *Jour. de Min.* No. xxxix. 177. † Vauquelin, *Jour. de Phys.* lii. 245.

‡ Kirwan, i. 247. and 248.—Dolomieu, *Magazin Encyclopedique*, ii. 17. and 145.; and *Jour. de Min.* No. xviii. 19.—Klaproth's *Beitrag*, ii. 12.

Class I.  
Order I.  
Crystals.

The primitive form of its crystals is a regular six-sided prism; and the form of its integrant molecules is a triangular prism, whose sides are squares, and bases equilateral triangles \*. The most common variety of its crystals is the regular six-sided prism, sometimes with the edges of the prism, or of the bases, or the solid angles, or both wanting, and small faces in their place †. The sides of the prism are generally channelled.

Properties.

Its texture is foliated. Its fracture conchoidal. Lustre usually from 3 to 4. Transparency from 2 to 4. Causes a double refraction. Hardness 12. Specific gravity 2.65 to 2.775. Colour green. Becomes electric by friction, but not by heat. Its powder does not phosphoresce when thrown on a hot iron ‡. At 150° Wedgewood it melts into an opaque coloured mass. According to Dolomieu, it is fusible *per se* by the blow-pipe §.

This mineral was formerly subdivided into two distinct species, the *emerald*, and *beryl* or *aqua marina*. Haüy demonstrated, that the emerald and beryl corresponded exactly in their structure and properties; and Vauquelin found that they were composed of the same ingredients: henceforth, therefore, they must be considered as varieties of the same species.

Emerald.

The variety formerly called *emerald* varies in colour from the pale to the perfect green. It comes chiefly from Peru; some specimens have been brought from Egypt. Dolomieu found it in the granite of Elba. When heated to 120° Wedgewood, it becomes *blue*,

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\* Haüy, *Jour. de Min.* No. xix. 72.<sup>1</sup>

† Romé de Lisle, ii. 445. and Haüy, *ibid.*

‡ Dolomieu, *Jour. de Min.* No. xviii. 19. § *Ibid.*

but recovers its colour when cold. A specimen, analysed by Vauquelin, was composed of

Genus X.  
SAG.  
Species II.

64.60 silica,  
14.00 alumina,  
13.00 glucina,  
3.50 oxide of chromum,  
2.56 lime,  
2.00 moisture or other volatile ingredient.

---

99.66 \*

The *beryl* is of a greyish green colour, and sometimes blue, yellow, and even white: sometimes different colours appear in the same stone †. It is found in Ceylon, different parts of India, Brazil, and especially in Siberia and Tartary, where its crystals are sometimes a foot long ‡. A specimen of beryl, analysed by Vauquelin, contained

69 silica,  
13 alumina,  
16 glucina,  
1.5

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99.5 §

It was by analysing this stone that Vauquelin discovered the earth which he called *glucina*.

#### Sp. 2. Euclase.

This stone, which has lately been brought from Peru by Dombey, was at first confounded with the emerald on account of its green colour. The primitive form of its crystals is a rectangular prism, whose bases are squares. It is very brittle; sufficiently hard to scratch

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\* *Ann. de Chim.* xxvi. 264.

† Dolomieu, *ibid.*

‡ *Ibid.*

§ *Ann. de Chim.* xxxviii. 168.

Class I.  
Order I.

quartz. Transparency considerable. Causes double refraction. Specific gravity 3.0625. Fusible by the blow-pipe into a white enamel. A small specimen, analysed by Vauquelin, yielded the following ingredients, . . . . .

36 silica

23 alumina

15 glucina

5 oxide of iron

---

79\*

The loss, which amounts to 21, was probably owing to the presence of an alkali, which the smallness of the specimen analysed did not permit Vauquelin to ascertain.

#### GENUS XI. SAB.

*Sp. 1.* Staurolite†.

*Andreolite* of Lametherie and Haüy—*Hyacinthe blanche cruciforme*, var. 9. of Romé de Lisle.

This stone has been found at Andreasberg in the Hartz. It is crystallized, and the form of its crystals has induced mineralogists to give it the name of *cross-stone*. Its crystals are two four-sided flattened prisms, terminated by four-sided pyramids, intersecting each other at right angles; the plane of intersection passing longitudinally through the prisms‡.

Properties.

Its texture is foliated. Its lustre waxy, 2. Transparency from 1 to 3. Hardness 9. Brittle. Specific gravity 2.355 to 2.361. Colour milk white. When heated slowly, it loses 0.15 or 0.16 parts of its weight, and falls into powder. It effervesces with borax and

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\* *Jour. de Phys.* lii. 317. † Kirwan, i. 282.

‡ See also Gillot, *Jour. de Phys.* 1793, p. 1. and 2.

microcosmic salt, and is reduced to a greenish opaque mass. With soda it melts into a frothy white enamel. When its powder is thrown on a hot coal, it emits a greenish yellow light\*.

Genus XII  
I. ASL.  
Species I.

A specimen analysed by Westrum was composed of

44 silica  
20 alumina  
20 barytes  
16 water

Composition.

---

100

Klaproth found the same ingredients, and nearly in the same proportions†.

A variety of staurolite has been found only once; Variety. which has the following properties.

Its lustre is pearly, 2. Specific gravity 2.361. Colour brownish grey. With soda it melts into a purplish and yellowish frothy enamel. It is composed, according to Westrum, of

47.5 silica  
12.0 alumina  
20.0 barytes  
16.0 water  
4.5 oxides of iron and manganese

---

100.0

GENUS XII. I. ASL.

Sp. 1. Chrysoberyl‡.

*Oriental chrysolite* of jewellers—*Cymophane* of Haüy—*Chrysopal* of Delametherie.

Hitherto this stone has been found only in Brazil, the

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\* Haüy, *Jour. de Min.* No. xxviii. 280.

† Beitrage, ii. 80.

‡ Kirwan, i. 261.



Class I.  
Order I.

Crystals.

Properties.

island of Ceylon, and as some affirm near Nortschink in Siberia. Werner first made it a distinct species, and gave it the name which it now bears. It is usually found in round masses about the size of a pea, but it is sometimes also crystallized. The primitive form of its crystals is a four-sided rectangular prism, whose height is to its breadth as  $\sqrt{3}$  to 1, and to its thickness as  $\sqrt{2}$  to 1. The only variety hitherto observed is an eight-sided prism, terminated by six-sided summits. Two of the faces of the prism are hexagons, two are rectangles, and four trapeziums; two faces of the summits are rectangles, and the other four trapeziums. Sometimes two of the edges of the prism are wanting, and small faces in their place\*.

Its texture is foliated. Laminæ parallel to the faces of the prism. Lustre 3 to 4. Transparency 3 to 4. Causes single refraction. Hardness 12. Specific gravity from 3.698 † to 3.796 †. Colour yellowish green, surface sparkling. It is infusible by the blow-pipe *per se*, and with soda.

A specimen of chrysoberyl, analysed by Klaproth, was composed of

71.5	alumina
18.0	silica
6.0	lime
1.5	oxide of iron

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97.0 §

### GENUS XIII. 2. SAL.

Sp. 2. Hyalite ||.

This stone is found frequently in trap. It occurs in grains, filaments, and rhomboidal masses. Texture fo-

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\* Haüy. *Jour. de Min.* No. xxi. 5.

§ Beitrage, i. 102.

† Werner.

‡ Haüy

¶ Kirwan, i. 296.

liated. Fracture uneven, inclining to conchoidal. Lustre glassy\*, 2 to 3. Transparency 2 to 3; sometimes, tho' seldom, it is opaque. Hardness 9. Specific gravity 2.11†. Colour pure white. Infusible at 150° Wedgewood; but it yields to soda‡. According to Mr Link, it is composed of

57 silica

18 alumina

15 lime

90 and a very little iron§

Sp. 3. Ædelite||.

This stone has hitherto been found only in Sweden at Mosseberg and Ædelfors. From this last place Mr Kirwan, who first made it a distinct species, has given it the name of ædelite. It was first mentioned by Bergman¶. Its form is tuberosé and knotty. Texture striated; sometimes resembles quartz. Lustre from 0 to 1. Specific gravity 2.515 after it has absorbed water\*\*. Colour light grey, often tinged red; also yellowish brown, yellowish green and green. Before the blow-pipe it intumesces and forms a frothy mass. Acids convert it into a jelly††. A specimen from Mosseberg, analysed by Bergman, contained

69 silica

20 alumina

8 lime

3 water

100††

\* Hence probably the name *hyalite*, which was imposed by Werner from *υαλις* glass, and *λιθος* a stone.

† Kirwan. ‡ Id.

§ Crell's *Annals*, 1790, 2 Band. 232.

|| Kirwan, i. 276.

¶ *Opusc.* vi. 101.

\*\* Kirwan, i. 276.

†† Bergman, iii. 227.

‡‡ *Opusc.* vi. 101.

Class I.  
Order I.

A specimen from Ædelfors yielded to the same che-

mist . . . . . 62 silica  
18 alumina  
16 lime  
4 water

---

100 \*

*Sp. 4. Scapolite.*

This mineral has been found at Arendal in Norway. It is of a pearl white colour, and is crystallized in long rectangular prisms. Its specific gravity is 3.680, and it is hard enough to scratch glass.

According to Abelgaard, it is composed of

38 silica  
30 alumina  
14 lime  
1 oxide of iron  
2 water

---

95 †

GENUS. XII. 3. SAWL.

*Sp. 5. Zeolite ‡.*

This stone was first described by Cronstedt in the Stockholm Transactions for 1756. It is found sometimes amorphous and sometimes crystallized. The primitive form of its crystals is a rectangular prism, whose bases are squares. The most common variety is a long four-sided prism, terminated by low four-sided pyramids §.

Crystals.

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\* *Opusc. vi. 101.* † *Jour. de Phys. lii. 33.*

‡ Kirwan, i. 278.—Guetard, iv. 637.—Bucquet, *Mem. Sav. Etrang.* ix. 576.—Pelletier, *Jour. de Phys. xx. 420.*

§ Haüy, *Jour. de Min. No. xiv. 86.*

Its texture is striated or fibrous. Its lustre is silky, from 3 to 1. Transparency from 2 to 4; sometimes 1. Hardness 6 to 8; sometimes only 4. Absorbs water. Specific gravity 2.07 to 2.3. Colour white, often with a shade of red or yellow; sometimes brick red, green, blue. When heated, it becomes electric like the tourmaline\*. Before the blow-pipe it froths†, emits a phosphorescent light, and melts into a white semitransparent enamel, too soft to cut glass, and soluble in acids. In acids it dissolves slowly and partially without effervescence; and at last, unless the quantity of liquid be too great, it is converted into a jelly.

Genus XII.  
3. SAWL.  
Species VI.  
Properties.

A specimen of zeolite‡, analysed by Vauquelin, contained . . . . .

53.00 silica

27.00 alumina

9.46 lime

10.00 water

99.46 §

Composi-  
tion.

### Sp. 6. Stilbite.

This stone was first formed into a distinct species by Mr Haüy. Formerly it was considered as a variety of zeolite.

The primitive form of its crystals is a rectangular prism, whose bases are rectangles. It crystallizes, sometimes in dodecahedrons, consisting of a four-sided prism

Crystals.

\* Haüy, *Jour. de Min.* No. xxviii. 276.

† Hence the name *zeolite*, given to this mineral by Cronstedt; from *ζεω* to ferment, and *λίθος* a stone.

‡ Dr Black was accustomed to mention, in the course of his lectures, that Dr Hutton had discovered *soda* in zeolite. This discovery has not hitherto been verified by any other chemical mineralogist.

§ *Jour. de Min.* No. xlv. 576.

Class I.  
Order I.

with hexagonal faces, terminated by four-sided summits, whose faces are oblique parallelograms; sometimes in six-sided prisms, two of whose solid angles are wanting, and a small triangular face in their place\*.

Properties.

Its texture is foliated. The laminæ are easily separated from each other, and are somewhat flexible. Lustre pearly, 2 or 3 †. Hardness inferior to that of zeolite, which scratches stilbite. Brittle. Specific gravity 2.500 ‡. Colour pearl white. Powder bright white, sometimes with a shade of red. This powder, when exposed to the air, cakes and adheres as if it had absorbed water. It causes syrup of violets to assume a green colour. When stilbite is heated in a porcelain crucible, it swells up and assumes the colour and semitransparency of baked porcelain. By this process it loses 0.185 of its weight. Before the blow-pipe it froths like borax, and then melts into an opaque white coloured enamel §.

Composition.

According to the analysis of Vauquelin, it is composed of . . . . .

52.0	silica
17.5	alumina
9.0	lime
18.5	water
<hr/>	
97.0	¶

Sp. 7. Chabasie.

This mineral, which was first separated from the succeeding species by Bosc d'Antic and Haüy, is found at

\* Haüy, *Jour de Min.* No. xiv. 86.

† Hence the name given to this mineral by Haüy, *stilbite*, from *στίλβω* to shine.

‡ Haüy, *Ibid.* No. xxviii. 276.

§ Vauquelin, *Ibid.* No. xxxix. 161.

¶ *Ibid.* 164.



Oberstein in Germany. It has a white colour, and laminated texture. The primitive form of its crystals is a rhomboid slightly obtuse. Specific gravity 2.1176. Scarcely scratches glass.

Genus XII.  
4. SLA.  
Species IX.

*Sp. 8. Analcime.*

This stone, which was discovered by Mr Dolomieu, is found crystallized in the cavities of lava. It was first made a distinct species by Mr Haüy. Mineralogists had formerly confounded it with zeolite,

The primitive form of its crystals is a cube. It is sometimes found crystallized in cubes, whose solid angles are wanting, and three small triangular faces in place of each; sometimes in polyhedrons with 24 faces. It is usually somewhat transparent. Hardness about 8; scratches glass slightly. Specific gravity above 2. When rubbed, it acquires only a small degree of electricity, and with difficulty\*. Before the blow-pipe it melts without frothing into a white semitransparent glass†.

GENUS XII. 4. SLA.

*Sp. 9. Lazulite ‡.*

This stone, which is found chiefly in the northern parts of Asia, has been long known to mineralogists by the name of *lapis lazuli*. This term has been contracted into *lazulite* by Mr Haüy; an alteration which was certainly proper, and which therefore I have adopted.

Lazulite is always amorphous. Its texture is earthy. Its fracture uneven. Lustre o. Opaque, or nearly so. Hardness 8 to 9. Specific gravity 2.76 to 2.945 §. Co-

Properties.

\* Hence the name *analcime* given it by Haüy, from *αναλκίς* weak.

† Haüy, *Faur. de Min.* No. xiv. 86. and xxviii. 278.

‡ Kirwan, i. 283. § Brisson.

Class I.  
Order I.

lour blue \* ; often spotted white from specks of quartz, and yellow from particles of pyrites.

It retains its colour at  $100^{\circ}$  Wedgewood ; in a higher heat it intumesces, and melts into a yellowish black mass. With acids it effervesces a little, and if previously calcined, forms with them a jelly.

Margraff published an analysis of lazulite in the Berlin Memoirs for 1758. His analysis has since been confirmed by Klaproth, who found a specimen of it to contain . . . . . 46.0 silica

Composi-  
tion.

14.5 alumina

28.0 carbonat of lime

6.5 sulphat of lime

3.0 oxide of iron

2.0 water

---

100.0†

From the experiments of Morveau, it appears that the colouring matter of lazulite is sulphuret of iron.

### GENUS XIII. SALI.

#### *Sp. 1. Garnet†.*

Crystals. This stone is found abundantly in many mountains. It is usually crystallized. The primitive form of its crystals is a dodecahedron whose sides are rhombs, with angles of  $78^{\circ} 31' 44''$ , and  $120^{\circ} 28' 16''$ . The inclination of the rhombs to each other is  $120^{\circ}$ . This dode-

---

\* Hence the name *lazulite*, from an Arabian word *azul*, which signifies blue.

† Beitrage, i. 196.

‡ Kirwan, i. 258.—Gerhard, *Disquisitio Physico-chymica Granatorum*, &c.—Pasumot, *Jour. de Phys.* iii. 442.—Wiegleb, *Ann. de Chim.* i 231.

cahedron may be considered as a four-sided prism, terminated by four-sided pyramids \*. It is divisible into four parallelepipeds, whose sides are rhombs; and each of these may be divided into four tetrahedrons, whose sides are isosceles triangles, equal and similar to either of the halves into which the rhomboidal faces of the dodecahedron are divided by their shorter diagonal. The integrant molecules of garnet are similar tetrahedrons †. Sometimes the edges of the dodecahedron are wanting, and small faces in their place; and sometimes garnet is crystallized in polyhedrons, having 24 trapezoidal faces. For a description and figure of these, and other varieties of garnet, the reader is referred to Romé de Lisle and Haüy ‡.

Genus XIII.  
SALT.  
Species I.

The texture of garnet, as Bergman first shewed, is foliated §. Its fracture commonly conchoidal. Internal lustre from 4 to 2. Transparency from 2 to 4; sometimes only 1 or 0. Causes single refraction ||. Hardness from 10 to 14. Specific gravity 3.75 to 4.188. Colour usually red. Often attracted by the magnet. Fusible *per se* by the blow-pipe.

*Variety 1.* Oriental garnet \*\*.—Internal lustre 3 to 4. Transparency 4. Hardness 13 to 14. Specific gravity 4 to 4.188. Colour deep red, inclining to violet ††.

Properties

Varieties.

\* Romé De Lisle, ii. 322. and Haüy, *Ann. de Chim.* xvii. 305.

† Haüy, *Ibid.* 306. ‡ *Ibid.* 307. § *Opusc.* ii. 9.

|| Haüy, *Jour. de Min.* No. xxviii. 260.

\*\* This seems to be the *carbuncle* (σφραῖς) of Theophrastus, and the *carbunculus garamanticus* of other ancient writers.—See Hill's *Theophrastus*, πρὸς λίθων, p. 74. and 77.

†† Hence, according to many, the name *garnet* (in Latin *granatus*), from the resemblance of the stone in colour to the blossoms of the pomegranate.

Class I.  
Order I.

*Variety 2.* Common garnet.—Fracture uneven, inclining to the conchoidal. Internal lustre 2 to 3. Transparency from 3 to 0. Hardness 10 to 11; sometimes only 9. Specific gravity 3.75 to 4. Colour commonly deep red, inclining to violet: sometimes verging towards black or olive; sometimes leek-green, brown, yellow.

*Variety 3.* Amorphous garnet.—Structure slaty. Lustre 2. Transparency 2 to 1. Hardness 11 to 12. Specific gravity 3.89. Colour brownish or blackish red. Found in Sweden, Switzerland, and the East Indies.

Composition.

A specimen of oriental garnet, analysed by Klaproth, contained . . . . . 35.75 silica

27.25 alumina

36.00 oxide of iron

10.25 oxide of manganese

—  
99.25\*

A specimen of red garnet, analysed by Vauquelin, contained . . . . . 52.0 silica

20.0 alumina

17.0 oxide of iron

7.7 lime

—  
96.7†

*Sp. 2.* Pyrop.

This mineral, which is found in Saxony and Bohemia, has been lately separated from the garnet by Werner, and made a distinct species. It is never found crystallized, but only in round or angular fragments, usually

\* Beitrage, ii. 26.

† Jour. de Min. No. xlv. 575.

small. Colour deep red\*, which passes to orange when the mineral is exposed to the sun. Very hard. Specific gravity unknown. Fracture conchoidal, and very brilliant†.

Genus XIII.  
SALL.  
Species IV.

Sp. 3. Melanite.

This mineral was formerly confounded with the garnet. It is found at Frascati in Italy, stuck in lava. It is of a black colour, and crystallized like the garnet, in a dodecahedron, having its edges truncated. This mineral was analysed by Vauquelin, and yielded

43 silica

16 alumina

120 lime

16 oxide of iron

4 moisture

99‡

Sp. 4. Thummerstone§.

*Yanolite* of Lametherie—*Axinite* of Haüy.

This stone was first described by Mr Schreber, who found it near Balme d'Auris in Dauphiné, and gave it the name of *shorl violé* ||. It was afterwards found near Thum in Saxony, in consequence of which Werner called it *thummerstone*.

History.

It is sometimes amorphous; but more commonly crystallized. The primitive form of its crystals is a rectangular prism, whose bases are parallelograms with angles of  $101^{\circ} 32'$  and  $78^{\circ} 28'$  ¶. The most usual va-

Crystals.

\* Hence the name *κρυσταλλ*. † *Jour. de Phys.* lii. 227.

‡ *Jour. de Min.* No. xlv. 573.

§ Kirwan, i. 273.—Pelletier, *Jour. de Phys.* xvi. 66.

|| Romé De Lisle, ii. 353. ¶ Haüy, *Jour. de Min.* No. xxviii. 264.



Class I.  
Order I.

riety is a flat rhomboidal parallelopiped, with two of its opposite edges wanting, and a small face in place of each \*. The faces of the parallelopiped are generally streaked longitudinally.

Properties.

The texture of thummerstone is foliated. Its fracture conchoidal. Lustre 2. Transparency, when crystallized, 3 to 4; when amorphous, 2 to 1. Causes simple refraction†. Hardness 10 to 9. Specific gravity 3.2956. Colour clove brown; sometimes inclining to red, green, grey, violet, or black. Before the blow-pipe it froths like zeolite, and melts into a hard black enamel. With borax it exhibits the same phenomena, or even when the stone is simply heated at the end of a pincer. ‡.

Composition.

A specimen of thummerstone, analysed by Klaproth, contained . . . . 52.7 silica  
25.6 alumina  
9.4 lime  
9.6 oxide of iron with a trace of  
manganese  
97.3 §

A specimen, analysed by Vauquelin, contained

44 silica  
18 alumina  
19 lime  
14 oxide of iron  
4 oxide of manganese

99 ||

\* Romé De Lisle, ii. 353.

† Haüy, *Jour. de Min.* xviii. 264.

‡ Vauquelin, *Jour. de Min.* No. xxiii. 1.

§ *Beitrag*, ii. 126.

|| *Jour. de Min.* *ibid.*

*Sp. 5.* Prehnite \*.

Genus XIII.

SALI.

Species V.

History.

Though this stone had been mentioned by Sage †, Romé de Lisle ‡, and other mineralogists, Werner was the first who properly distinguished it from other minerals, and made it a distinct species. The specimen which he examined was brought from the Cape of Good Hope by Colonel Prehn; hence the name *prehnite*, by which he distinguished it. It was found near Dunbarton by Mr Grotche §; and since that time it has been observed in other parts of Scotland.

It is both amorphous and crystallized. The crystals are in groups, and confused: they seem to be four-sided prisms with dihedral summits ||. Sometimes they are irregular six-sided plates, and sometimes flat rhomboidal parallelepipeds. Crystals.

Its texture is foliated. Fracture uneven. Internal lustre pearly, scarcely 2. Transparency 3 to 2. Hardness 9 to 10. Brittle. Specific gravity 2.6969 ¶. Colour apple green, or greenish grey. Before the blow-pipe it froths more violently than zeolite, and melts into a brown enamel. A specimen of prehnite, analysed by Klaproth, was composed of Properties.

43.83 silica  
30.33 alumina  
18.33 lime  
5.66 oxide of iron  
1.16 air and water

Composition.

---

99.31 \*\*

\* Kirwan, i. 274.—Hassenfratz, *Jour. de Phys.* xxxii. 81.—Sage, *ibid.* xxxiv. 446.—Klap. *Beob. der Berl.* 2 Band. 211.; and *Ann. de Chim.* i. 201.

† *Miner.* i. 232.

‡ *Crystallog.* ii. 275.

§ *Ann. de Chim.* i. 213.

|| Haüy, *Jour. de Min.* No. xxviii. 277.

¶ Haüy, *ibid.*

\*\* *Ann. de Chim.* i. 208.

Class I.  
Order I.

Whereas Mr Hassenfratz found in another specimen

50.0 silica

20.4 alumina

23.3 lime

4.9 iron

.9 water

.5 magnesia

---

100.0 \*

Sp. 6. Thallite.

*Green shorl* of Dauphiné of De Lisle †—*Delphinite* of Saussure.

This stone is found in the fissures of mountains; and hitherto only in Dauphiné and on Chamouni in the Alps.

Crystals.

It is sometimes amorphous, and sometimes crystallized. The primitive form of its crystals is a rectangular prism, whose bases are rhombs with angles of  $114^{\circ} 37'$ , and  $65^{\circ} 23'$  ‡. The most usual variety is an elongated four-sided prism (often flattened), terminated by four-sided incomplete pyramids; sometimes it occurs in regular six-sided prisms §. The crystals are often very slender.

Properties.

Its texture appears fibrous. Lustre inconsiderable. Transparency 2 to 3, sometimes 4; sometimes nearly opaque. Causes single refraction. Hardness 9 to 10. Brittle. Specific gravity 3.4529 to 3.46. Colour dark green ||. Powder white or yellowish green, and feels dry. It does not become electric by heat. Be-

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\* *Ann. de Chim.* i. 208. and *Four. de Phys.* No. xxxii. 81.

† *Crystallog.* ii. 401.

‡ Haüy, *Four. de Min.* No. xxviii. 271.

§ Romé de Lisle, *ibid.* and Haüy, *Four. de Min.* No. xxx. 415.

|| Hence the name *thallite*, given it by Lametherie, from *θαλλος*, a green leaf.

fore the blow-pipe, froths and melts into a black slag. Genus XIV.

With borax melts into a green bead \*. I. AMS.

A specimen of thallite, analysed by Mr Descotils, Species I.

contained . . . . .	37	silica	Composi- tion.
	27	alumina	
	17	oxide of iron	
	14	lime	
	1.5	oxide of manganese	
	96.5	†	

*Sp. 7. Skorza.*

This is a green coloured mineral, whose specific gravity is 3.35. Klaproth found it composed of

43.00	silica
21.00	alumina
14.00	lime
16.50	oxide of iron
0.25	oxide of manganese
94.75	‡

GENUS XIV. I. AMS.

*Sp. i. Cyanite§.*

*Sappare* of Saussure,

This stone was first described by Mr Saussure the son, who gave it the name of *sappare*||. It is commonly found in granite rocks. The primitive form of its crystals is a four-sided oblique prism, whose sides are inclined at an angle of  $103^{\circ}$ . The base forms with one

Crystals.

\* Haüy and Descotils, *Jour. de Min.* No. xxx. 415.

† Ibid. No. xxx. 420.

‡ *Jour. de Phys.* lii. 39.

§ Kirwan, i. 209.—Sage, *Jour. de Phys.* xxxv. 39.

|| *Jour. de Phys.* xxxiv. 213.

Class I.  
Order I.

Properties.

side of the prism an angle of  $103^{\circ}$ ; with another, an angle of  $77^{\circ}$ . It is sometimes crystallized in six-sided prisms\*.

Its texture is foliated. Laminæ long. Fragments long, splintery. Lustre pearly, 2 to 3. Transparency of the laminæ 3. Causes single refraction†. Hardness 6 to 9. Brittle. Specific gravity from 3.092 to 3.622‡. Feels somewhat greasy. Colour milk white, with shades of sky or prussian blue§; sometimes bluish grey; sometimes partly bluish grey, partly yellowish or greenish grey.

Composition.

Before the blow-pipe it becomes almost perfectly white, but does not melt. According to the analysis of Saussure, it is composed of

13.25 magnesia

12.81 silica

5.48 iron

1.71 lime

---

100.17 ||.

Cyanite has also been analysed by Struvius and Hermann, who agree with Saussure as to the ingredients; but differ widely from him and one another as to the proportions.

Struvius.

Hermann.

5.5 . . . . . 30 alumina

30.5 . . . . . 39 magnesia

51.5 . . . . . 23 silica

5.0 . . . . . 2 iron

4.0 . . . . . 3 lime

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96.5 ¶

---

97 \*\*

\* Haüy, *Jour. de Min.* No. xxviii. 282.

† Haüy, *ibid.*

‡ Kirwan.

§ Hence the name *cyanite*, imposed by Werner.

|| *Jour. de Phys.* xxxiv. 213.

¶ *Crell's Annals*, 1790.

\*\* *Ibid.*



## GENUS XIV. 2. MSA.

Genus XV.

MSAI.

Species I.

Properties.

## Sp. 2. Serpentine\*.

This stone is found in amorphous masses. Its fracture is splintery. Lustre 0. Opaque. Hardness 6 to 7. Specific gravity 2.2645 to 2.709. Feels rather soft, almost greasy. Generally emits an earthy smell when breathed upon. Its colours are various shades of green, yellow, red, grey, brown, blue: commonly one or two colours form the ground, and one or more appear in spots or veins†.

Before the blow-pipe it hardens and does not melt.

A specimen of serpentine, analysed by Mr Chenevix, contained . . .

34.5 magnesia  
28.0 silica  
23.0 alumina  
4.5 oxide of iron  
0.5 lime  
10.5 water

Composition.

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101.0‡

## GENUS XV. MSAI.

## Sp. 1. Potstone§.

This stone is found in nests and beds, and is always amorphous. Its structure is often slaty. Texture undulatingly foliated. Lustre from 1 to 3. Transparency from 1 to 0; sometimes 2. Hardness 4 to 6.

Properties.

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\* Kirwan, i. 156.—Margraff, *Mem. Berlin*, 1759, p. 3.—Bayen, *Jour. de Phys.* xiii. 46.—Mayer, *Crell's Annals*, 1789, ii. 416.

† Hence the name *serpentine*, given to this stone from a supposed resemblance in colours to the skin of serpent.

‡ *Ann. de Chim.* xxviii. 199. § Kirwan, i. 155.

Class I.  
Order I.

Brittle. Specific gravity from 2.8531 to 3.023. Feels greasy. Sometimes absorbs water. Colour grey with a shade of green, and sometimes of red or yellow; sometimes leek green; sometimes speckled with red.

Potstone is not much affected by fire; and has therefore been made into utensils for boiling water; hence its name.

Composi-  
tion.

According to Wiegleb, the potstone of Como contains

38 magnesia  
38 silica  
7 alumina  
5 iron  
1 carbonat of lime  
1 fluoric acid

---

90

*Sp. 2. Chlorite\*.*

This mineral enters as an ingredient into different mountains. It is sometimes amorphous, and sometimes crystallized in oblong, four-sided, acuminate crystals.

**Properties.** Its texture is foliated. Its lustre from 0 to 2. Opaque. Hardness from 4 to 6; sometimes in loose scales. Colour green.

**Varieties.** *Variety 1.* Farinaceous chlorite.—Composed of scales scarcely cohering, either heaped together, or investing other stones. Feels greasy. Gives an earthy smell when breathed on. Difficult to pulverise. Colour grass green; sometimes greenish brown; sometimes dark green, inclining to black. Streak white. When the powder of chlorite is exposed to the blow-

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\* Kirwan, i. 147.

pipe it becomes brown. Before the blow-pipe, farinaceous chlorite froths and melts into a dark brown glass; with borax it forms a greenish brown glass\*.

Genus XV.  
MSAL.  
Species II.

*Variety 2.* Indurated chlorite.—This variety is crystallized. Lustre 1. Hardness 6. Feel meagre. Colour dark green, almost black. Streak mountain green.

*Variety 3.* Slaty chlorite—Structure slaty. Fragments flatted. Internal lustre 1 to 2. Hardness 5. Colour greenish grey, or dark green inclining to black. Streak mountain green.

A specimen of the first variety, analysed by Vauquelin, contained . . . . 43.3 oxide of iron

Composi-  
tion.

26.0 silica

15.5 alumina

8.0 magnesia

2.0 muriat of potass

4.0 water

---

98.8 †

A specimen of the same variety yielded Mr Hæpner

12.92 oxide of iron

37.50 silica

4.17 alumina

43.75 magnesia

1.66 lime

---

100.00 ‡

A specimen of the second variety, analysed by the same chemist, contained

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\* Vauquelin, *Jour. de Min.* No. xxxix. 167.

† *Ann. de Chim.* xxx. 106.

‡ Saussure's *Voyages*, ii. 133.

Class I.  
Order I.

	10.15	oxide of iron
	41.15	silica
	6.13	alumina
	39.47	magnesia
	1.50	lime
	1.50	air and water

---

99.9 \*

On the supposition that these analyses are accurate, the enormous difference between them is a demonstration that chlorite is not a chemical combination, but a mechanical mixture.

#### GENUS XVI. SLAM.

##### *Sp. 1.* Siliceous spar.

This stone has been found in Transylvania. It is crystallized in four or six-sided prisms, channelled transversely, and generally heaped together. Its texture is fibrous. Its lustre silky, 2. Its colours white, yellow, green, light blue. According to Bindheim, it contains

61.1	silica
21.7	lime
6.6	alumina
5.0	magnesia
1.3	oxide of iron
3.3	water.

---

99.0 †

#### GENUS XVII. 1. SAMLI.

##### *Sp. 1.* Argillite ‡.

*Argillaceous schistus—Common slate.*

This stone constitutes a part of many mountains.

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\* Crell's *Annals*, 1790, p. 56.

† Berg. vi. 104.

‡ Kirwan, i. 234.

Its structure is slaty. Its texture foliated. Fracture splintery. Fragments often tabular. Lustre most commonly silky, 2 ; sometimes 0. Transparency from 0 to 1. Hardness from 5 to 8. Specific gravity from 2.67 to 2.88. Does not adhere to the tongue. Gives a clear sound when struck. Often imbibes water. Streak white or grey. Colour most commonly grey, with a shade of blue, green, or black ; sometimes purplish, yellowish, mountain green, brown, bluish black ; sometimes striped or spotted with a darker colour than the ground.

It is composed, according to Kirwan, of silica, alumina, magnesia, lime, oxide of iron. In some varieties the lime is wanting. Several varieties contain a considerable quantity of carbonaceous matter.

Gen. XVIII.  
SLACMI.  
Species I.  
Properties.

GENUS XVIII. SLACMI.

*Sp. I.* Smaragdite.

This stone was called *smaragdite* by Mr Saussure, from some resemblance which it has to the emerald. Never crystallized. Its texture is foliated. Easily divided into plates. The laminæ are inflexible. Fracture even. Hardness 7. Specific gravity 3. Colour in some cases fine green ; in others it has the grey colour and metallic lustre of mica : it assumes all the shades of colour between these two extremes\*.

According to the analysis of Vauquelin, it is composed of

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\* Haüy, *Jour. de Min.* No. xxviii. 272.



Class I.  
Order I.

50.0	silica
13.0	lime
11.0	alumina
7.5	oxide of chromum
6.0	magnesia
5.5	oxide of iron
1.5	oxide of copper
94.5	*

## GENUS XIX. SM.

Sp. I. Kiffekil †.

*Myrsen—Seafroth.*

This mineral is dug up near Konie in Natolia, and is employed in forming the bowls of Turkish tobacco pipes. The sale of it supports a monastery of dervises established near the place where it is dug. It is found in a large fissure six feet wide, in grey calcareous earth. The workmen assert that it grows again in the fissure †, and puffs itself up like froth §. This mineral, when fresh dug, is of the consistence of wax; it feels soft and greasy; its colour is yellow; its specific gravity 1.600 || : when thrown on the fire it sweats, emits a fetid vapour, becomes hard, and perfectly white.

According to the analysis of Klaproth, it is composed of . . . . .

50.50	silica
17.25	magnesia
25.00	water
5.00	carbonic acid
.50	lime.
98.25	¶

\* *Ann. de Chim.* xxx. 106.† Kirwan's *Min.* i. 144.‡ Reigneegg, *Philos. Mag.* iii. 165.§ Hence the name *kiff-kil*, or rather *keff-kelli*, "clay froth," or "light clay."

|| Klaproth.

¶ *Beitrag*, ii. 172.

Genus XIX.  
SM.  
Species II.

*Sp. 2. Steatites\*.*

Though this mineral was noticed by the ancients, little attention was paid to it by mineralogists, till Mr Pott published his experiments on it in the Berlin Memoirs for 1747.

It is usually amorphous, but sometimes it is crystallized in six-sided prisms. Its texture is commonly earthy, but sometimes foliated. Lustre from 0 to 2. Transparency from 0 to 2. Hardness 4 to 7. Specific gravity from 2.61 to 2.794 †. Feels greasy. Seldom adheres to the tongue. Colour usually white or grey; often with a tint of other colours; the foliated commonly green. Does not melt *per se* before the blow-pipe. Properties.

*Variety 1.* Semi-indurated steatites. Texture earthy. Varieties.  
Fracture sometimes coarse splintery. Lustre 0. Transparency 0, or scarce 1. Hardness 4 to 5. Absorbs water. Takes a polish from the nail. Colour white, with a shade of grey, yellow, or green; sometimes pure white; sometimes it contains dendritical figures; and sometimes red veins.

*Variety 2.* Indurated steatites. Fracture fine splintery, often mixed with imperfectly conchoidal. External lustre 2 to 1, internal 0. Transparency 2. Often has the feel of soap. Absorbs water. Colour yellowish or greenish grey; often veined or spotted with deep yellow or red.

*Variety 3.* Foliated or striated steatites. The texture of this variety is usually foliated; sometimes striated.

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\* Kirwan, i. 151.—Pott. *Mem. Berlin*, 1747, p. 57.—Wiegleb, *Jour. de Phys.* xxix. 60.—Lavoisier, *Mem. Par.* 1778, 433.

† Brisson.

Class I.  
Order I.

Fragments cubiform. Lustre 3. Transparency 2 to 1. Hardness 6 to 7. Colour leek green, passing into mountain green or sulphur yellow. Streak pale greenish grey. When heated to redness, it becomes grey; and at 147° Wedgewood, it forms a grey porous porcelain mass\*.

Composition.

A specimen of steatites analysed by Klaproth, contained . . . . .

59.3	silica
30.5	magnesia
2.5	iron
5.5	water

---

98.0 †

A specimen of white steatites, analysed by Mr Che-  
nevix, contained . . .

60.00	silica
28.50	magnesia
3.00	alumina
2.50	lime
2.25	iron

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96.25 ‡

## GENUS XX. MSI.

### Sp. I. Chrysolite §.

*Peridot* of the French—*Topaz* of the ancients.

The name *chrysolite* was applied, without discrimination, to a great variety of stones, till Werner defined it accurately, and confined it to that stone which the French chemists distinguish by the appellation of *peridot*. This stone is the *topaz* of the ancients; their *chrysolite* is now called *topaz* ||.

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\* Kirwan, i. 155. † Beitrage, ii. 179. ‡ Ann. de Chim. xxviii. 200.

§ Kirwan, i. 262.—Cartheuser, Min. 94.—Dolomieu, Jour. de Min. No. xxix. 365.—La Metheric, Nouv. Jour. de Phys. i. 397.

|| Plinii, lib. xxxvii. c. 8.

Chrysolite is found sometimes in unequal fragments, and sometimes crystallized. The primitive form of its crystals is a right-angled parallelopiped, whose length, breadth, and thickness, are as 5,  $\sqrt{8}$ ,  $\sqrt{5}$ \*.

Genus XX.  
Msr.  
Species I.  
Crystals.

The texture of the chrysolite is foliated. Its fracture conchoidal. Its internal lustre from 2 to 4. Its transparency from 4 to 2. Causes double refraction. Hardness 9 to 10. Brittle. Specific gravity from 3.265 to 3.45. Colour green. It is infusible at  $150^{\circ}$ , but loses its transparency, and becomes blackish grey†. With borax it melts without effervescence into a transparent glass of a light green colour. Infusible with microcosmic salt‡ and fixed alkali§.

Properties.

*Variety 1.* Common chrysolite. Found in Ceylon, and South America, and in Bohemia, amidst sand and gravel||. Lustre 3 to 4. Transparency 4 to 3. Colour yellowish green, sometimes verging to olive green, sometimes to pale yellow.

Varieties.

*Variety 2.* Olive chrysolite. *Olivine* ¶.—Found commonly among traps and basalts; sometimes in small grains, sometimes in pretty large pieces; but it has not been observed in crystals. Lustre 2 to 3. Transparency 3 to 2. Colour olive green.

The first variety, according to the analysis of Klaproth, is composed of

Composition.

41.5 magnesia

38.5 silica

19.0 oxide of iron

99.0 \*\*

\* Haüy, *Jour. de Min.* No. xxviii. 281.

† Kirwan's *Min.* i. 263.

‡ Vauquelin, *Ann. de Chim.* xxi. 97.

§ Kirwan, i. 263.

|| Coquebert, *Jour. de Min.* No. xxii. 20.

¶ Kirwan, i. 263.—Le Lievre, *Jour. de Phys.* xxx. 397.

\*\* Klaproth's *Beitrag*, i. 103.

Class I.  
Order I.

According to that of Vauquelin, it is composed of

51.5 magnesia  
38.0 silica  
9.5 oxide of iron  

---

99.0 \*

The second variety, according to the analysis of Klaproth, is composed of

37.58 magnesia  
50.00 silica  
11.75 oxide of iron  
.21 lime  

---

99.54 †

Sp. 2. Jade†.

This stone was formerly called *lapis nephriticus*, and was much celebrated for its medical virtues. It is found in Egypt, China, America, and in the Siberian and Hungarian mountains. It is sometimes adhering to rocks, and sometimes in detached round pieces.

Properties

Its surface is smooth. Its fracture splintery. External lustre 0, or scarce 1; internal waxy, 1. Transparency from 2 to 1. Hardness 10. Not brittle. Specific gravity from 2.95 to 2.9829; or, according to Saussure, to 3.389. Feels greasy. Looks as if it had imbibed oil. Colour dark leek green, or verging towards blue; in some prominencies inclining to greenish or bluish white. When heated it becomes more transparent and brittle, but it is infusible *per se*. According to Hæpfner, it is composed of

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\* *Ann. de Chim.* xxi. 97. † *Beitrag*, i. 112.

‡ Kirwan, i. 171.—Bartolin, *De Lapide Nephritico*.—Lehmann, *Nov. Comm. Petropol.* x. 381.—Hæpfner, *Hist. Nat. de la Suisse*, i. 251.



47 silica	
38 carbonat of magnesia	
9 iron	
4 alumina	
2 carbonat of lime	

Genus XXI.  
SML.  
Species I.

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100

This is the stone which the inhabitants of New Zealand make into hatchets and other cutting instruments.

### GENUS XXI. SML.

#### *Sp. I. Asbestos\*.*

This mineral was well-known to the ancients. They even made a kind of cloth from one of the varieties, which was famous among them for its incombustibility. It is found abundantly in most mountainous countries, and nowhere more abundantly than in Scotland.

It is commonly amorphous. Its texture is fibrous. Its fragments often long splintery. Lustre from 0 to 2; sometimes 3, and then it is metallic. Transparency from 0 to 2. Hardness from 3 to 7. Specific gravity from 2.7 to 0.6806. Absorbs water. Colour usually white or green. Fusible *per se* by the blow-pipe.

*Variety 1. Common asbestos.*—Lustre 2 to 1. Varieties. Transparency 1. Hardness 6 to 7. Specific gravity 2.577 to 2.7. Feels somewhat greasy. Colour leek green; sometimes olive or mountain green; sometimes greenish or yellowish grey. Streak grey. Powder grey.

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\* Kirwan, i. 159.—Bergman, iv. 160.—Plot, *Phil. Trans.* xv. 1051.—Nebel, *Jour. de Phys.* ii. 62.—*Ibid.* iii. 367.

Class I.  
Order I.

*Variety 2.* Flexible asbestos. *Amiantus*—Composed of a bundle of threads slightly cohering. Fibres flexible. Lustre 1 to 2, sometimes 3. Transparency 1 to 2, sometimes 0. Hardness 3 to 4. Specific gravity, before it absorbs water, from 0.9088 to 2.3134; after absorbing water, from 1.5662 to 2.3803\*. Feels greasy. Colour greyish or greenish white; sometimes yellowish or silvery white, olive or mountain green, pale flesh red, and mountain yellow.

*Variety 3.* Elastic asbestos. *Mountain cork*—This variety has a strong resemblance to common cork. Its fibres are interwoven. Lustre commonly 0. Opaque. Hardness 4. Specific gravity, before absorbing water, from 0.6806 to 0.9933; after absorbing water, from 1.2492 to 1.3492. Feels meagre. Yields to the fingers like cork, and is somewhat elastic. Colour white; sometimes with a shade of red or yellow; sometimes yellow or brown.

Composition.

A specimen of the first variety from Dalecarlia, analysed by Bergman, contained

63.9	silica
16.0	carbonat of magnesia
12.8	carbonat of lime
6.0	oxide of iron
1.1	alumina
<hr/>	
99.8†	

A specimen of the second variety yielded to the same chemist . . . . .

64.0	silica
17.2	carbonat of magnesia
13.9	carbonat of lime
2.7	alumina
2.2	oxide of iron
<hr/>	
100.0‡	

\* Brisson.

† *Opusc.* iv. 170.

‡ *Ibid* p. 163.

A specimen of the third variety contained, according to the same analysis, 56.2 silica

Gen. XXII.  
I. SILM.  
Species I.

26.1 carbonat of magnesia

12.7 carbonat of lime

3.0 iron

2.0 alumina

---

100.0\*

Twelve different specimens of asbestus, analysed by Bergman, yielded the same ingredients, differing a little in their proportions†.

*Sp. 2. Asbestinite* ‡.

This stone is amorphous. Texture foliated or broad striated. Lustre silky, 3. Transparency 1 to 2. Hardness 5 to 6. Specific gravity from 2.806 to 2.880. Colour white, with shades of red, yellow, green, or blue. At 150° Wedgewood it melts into a green glass.

## GENUS XXII. I. SILM.

*Sp. 1. Augite.*

*Pyroxen* of Haüy.—*Volcanite* of Delametherie.

This mineral is only found in basalt and lava. It is usually in grains or in small crystals. The primitive form of its crystals is an oblique angled prism, whose bases are rhombs with angles of 92° 18' and 37° 42'§. It generally crystallizes in six or eight sided prisms, terminated by dihedral summits||. Its texture is foliated. Hardness 9. Fracture imperfectly conchoidal and brilliant. Usually somewhat transparent. Colour deep green, or greenish black. Powder greenish

\* *Opusc.* iv. 170.

† *Ibid.* p. 175.

‡ Kirwan, i. 165.

§ Haüy, *Jour. de Min.* xxviii. 269.

|| D Lisle, ii. 398.

Class I.  
Order I.

grey. Specific gravity 3.47. Commonly attracted by the magnet\*. Scarcely fusible by the blow-pipe†. With borax it melts into a yellowish glass, which appears red while it is hot ‡.

According to the analysis of Vauquelin, it is composed of . . . . 52.00 silica

14.66 oxide of iron

13.20 lime

10.00 magnesia

3.33 alumina

2.00 oxide of manganese

---

95.19§

*Sp. 2.* Asbestoid||.

This stone has obtained its name from its similarity to common asbestus. It is amorphous. Its texture is foliated or striated. Its lustre common or glassy, from 2 to 3. Transparency from 0 to 1. Hardness 6 to 7. Specific gravity from 3 to 3.31. Colour olive or leek green; when decomposing, brown. Before the blow-pipe it melts *per se* into a brown globule. With borax it forms a violet-coloured globule verging towards hyacinth¶. According to the analysis of Mr Macquart, it is composed of 46 silica

20 oxide of iron

11 lime

10 oxide of manganese

8 magnesia

---

95\*\*

\* Ferber,

† Le Lievre.

‡ Vauquelin.

§ *Jour. de Min.* xxxix. 172.

|| Kirwan, i. 166.

¶ Macquart, *Ann. de Chim.* xxii. 83.

\*\* Ibid.

There is a variety of this species which Kirwan calls metalliform asbestoid. Its lustre is semimetallic, 3. Opaque. Hardness 8 to 9. Specific gravity 3.356. Colour grey, sometimes inclining to red\*.

Gen. XXII.

2. SMIL.

Species III.

## GENUS XXII. 2. SMIL.

*Sp. 3. Shorlaceous actinolite†.—Rayonnante.*

This stone crystallizes in four or six sided prisms, thicker at one end than the other; hence it has been called by the Germans *strahlstein*, "arrow-stone." The crystals sometimes adhere longitudinally. Fracture hackly. External lustre glassy, 3 to 4; internal, 1 to 2. Transparency from 2 to 3; sometimes 1. Hardness from 7 to 10. Specific gravity 3.023 to 3.45. Colour leek or dark green.

This stone is often the matrix of iron, copper, and tin ores.

*Sp. 4. Lamellar actinolite‡.*

This stone resembles hornblende. It is amorphous. Texture foliated. Lustre various in different places. Transparency 0, or scarce 1. Specific gravity 2.916. Colour dark yellowish or greenish grey.

*Sp. 5. Glassy actinolite§.*

This stone is found amorphous, composed of fibres adhering longitudinally, or in slender four or six-sided prisms. Texture fibrous. Fragments long splintery, so sharp that they can scarcely be handled without injury. External lustre glassy or silky, 3 to 4; internal 0. Transparency 2. Exceedingly brittle. Specific gravity 2.95 to 3.493. Colour leek green; sometimes verging towards greenish or silver white; sometimes

Properties.

\* Kirwan, i. 167.

† Ibid. p. 168.

‡ Ibid. 167.

§ Ibid. p. 168.



Class I.  
Order I.

stained with yellowish or brownish red. According to Bergman it is composed of, 72.0 silica

12.7 carbonat of magnesia

6.0 carbonat of lime

7.0 oxide of iron

2.0 alumina

---

99.7\*.

*Sp. 6. Idocrase.*

*Hyacinthine of Delametherie—Sorlo piceo of Giceni.*

**Properties.** This mineral is found in lava, and was formerly confounded with the hyacinth. Its colour is brown or greenish, and it is usually crystallized in rectangular eight sided prisms, or rather four-sided prisms with their edges truncated. The primitive form of its crystals is the cube. Specific gravity from 3.39 to 3.409. Scratches glass. Lustre 2. Fracture imperfectly conchoidal. Transparent. Causes double refraction. Before the blow-pipe melts into a yellowish glass. According to the analysis of Stucke, it is composed of

**Composi-  
tion.**

26.5 silica

40.2 magnesia

16.2 oxide of iron

16.0 lime

---

98.9†

## GENUS XXIII. SL.

*Sp. 1. Shistose hornstone†.*

The structure of this stone is slaty. Lustre from 0. to 1. Commonly opaque. Hardness 9 to 10. Specific gravity from 2.596 to 2.641. Colour dark bluish or blackish grey. Infusible *per se*.

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\* *Opusc. iv. 171.*

† *Jour. de Phys. xlv. 69.*

‡ *Kirwan, i. 305.*

*Variety 1.* Siliceous shistus.—Commonly intersected by reddish veins of iron stone. Fracture splintery. Lustre 0. Transparency from 0 to 1.

Gen. XXIII.  
St.  
Species II.  
Varieties.

*Variety 2.* Basanite or Lydian stone.—Commonly intersected by veins of quartz. Fracture even; sometimes inclining to conchoidal. Lustre scarce 1. Hardness 10. Specific gravity 2.596. Powder black. Colour greyish black.

This, or a stone similar to it, was used by the ancients as a touchstone. They drew the metal to be examined along the stone, and judged of its purity by the colour of the metallic streak. On this account they called it *βασανος*, *the trier*. They called it also *Lydian stone*; because, as Theophrastus informs us, it was found most abundantly in the river Tmolus in Lydia\*.

A specimen of the first variety, analysed by Wiegand, contained . . .

75.0 silica
10.0 lime
4.6 magnesia
3.5 iron
5.2 carbon

Composition.

98.3

This species is rather a mechanical mixture than a chemical combination.

#### *Sp. 2.* Tremolite.

This mineral, found in the valley of Tremola in the Alps, has been described by Saussure†, and seems to be very intimately connected with the minerals arranged under the second division of the last Genus. It is white with a shade of green or red, and is either cry-

\* Hill's *Theophrastus περι λιθων*, p. 190.

† Saussure's *Voyages*, iv. 105.

Class I.  
Order I.

Composi-  
tion.

stallized or in irregular masses. Its crystals are four-sided oblique prisms, with angles of  $67^{\circ}$  and  $113^{\circ}$ . Specific gravity from 2.9 to 3.2. Texture fibrous. Fracture conchoidal. Fibres rigid, so that it irritates the skin when rubbed against it. Cuts glass. Lustre considerable. Somewhat transparent. Fibres easily separated, so that it appears soft. Phosphoresces when two pieces are rubbed in the dark against each other. Von Berchen and Struve have divided this species into five varieties, namely, the common, glassy, asbestiform, silky, and grey. A specimen analysed by Klaproth contained

65.0	silica
38.0	lime
0.5	magnesia
0.5	oxide of iron
6.0	water and carbonic acid

---

100.0

#### GENUS XXIV. Zs.

Sp. 1. Zircon \*.

*Jargon—Hyacinth.*

Crystals.

This stone is brought from Ceylon, and found also in France, Spain, and other parts of Europe. It is commonly crystallized. The primitive form of its crystals is an octahedron, composed of two four-sided pyramids applied base to base, whose sides are isosceles triangles. The inclination of the sides of the same pyramid to each other is  $124^{\circ} 12'$ ; the inclination of the sides of one pyramid to those of another  $82^{\circ} 50'$ . The solid angle at the apex is  $73^{\circ} 44'$  †. The varieties of the crystalline forms of zircon amount to seven. In some

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\* Kirwan, i. 257. and 333.

† Haüy, *Jour. de Min.* No. xxvi. 91.

cases there is a four-sided prism interposed between the pyramids of the primitive form; sometimes all the angles of this prism are wanting, and two small triangular faces in place of each; sometimes the crystals are dodecahedrons, composed of a flat four-sided prism with hexagonal faces, terminated by four-sided summits with rhomboidal faces; sometimes the edges of this prism, sometimes the edges where the prism and summit join, and sometimes both together, are wanting, and we find small faces in their place. For an accurate description and figure of these varieties, the reader is referred to Mr Haüy\*.

Gen. XXIV  
Zs.  
Species I.

The texture of the zircon is foliated. Internal lustre 3. Transparency from 4 to 2. Causes a very great double refraction. Hardness from 10 to 16. Specific gravity from 4.2 to 4.16; †. Colour commonly reddish or yellowish; sometimes it is limpid.

Properties.

Before the blow pipe it loses its colour, but not its transparency. With borax it melts into a transparent glass. Infusible with fixed alkali and microcosmic salt.

1. The variety formerly called *hyacinth* is of a yellowish red colour, mixed with brown. Its surface is smooth. Its lustre 3. Its transparency 3 to 4.

Varieties.

2. The variety formerly called *jargon of Ceylon* is either grey, greenish, yellowish brown, reddish brown, or violet. It has little external lustre. It is sometimes nearly opaque.

The first variety, according to the analysis of Vauquelin, is composed of

Composition.

64.5 zirconia  
32.0 silica  
2.0 oxide of iron  
95.5 ‡

\* Haüy. *Jour. de Min.* No. xxvi. 91.

† Ibid.

‡ Ibid. p. 106.

Class I.  
Order I.

A specimen analysed by Klaproth contained

70.0	zirconia
25.0	silica
0.5	oxide of iron
<hr/>	
95.5	*

The second variety, according to Klaproth, who discovered the component parts of both these stones, contains . . . . . 68.0 zirconia

31.5	silica
0.5	nickel and iron
<hr/>	
100.0	†

#### GENUS XXV. *Ysi.*

##### *Sp. i.* Gadolinite.

#### Properties.

This mineral was first observed by Captain Arhenius, lodged in a white felspar in the quarry of Ytterby in Sweden, and received the name of Gadolinite, because Gadolin was the chemist who first ascertained its composition. It occurs in thick kidney-form masses, or in parallel plates. Its colour is black; that of its powder greenish grey. Fracture conchoidal and glassy. Opaque. Scratched by iron, and in some cases even by the nail. Attracted by the magnet. Before the blow-pipe decrepitates and melts into a black blistered slag. Forms with borax a yellowish transparent glass; with soda a white transparent glass †. According to the analysis of Vauquelin, it is composed of

\* *Beitrag*, i. 231. † *Ibid.* i. 219.

† Ekeberg, *Crell's Annals*, 1799. ii. 67.



35.0	yttria
25.5	silica
25.0	oxide of iron
2.0	lime
2.0	oxide of manganese
10.5	water and carbonic acid
<hr/>	
100.0	*

Gen. XXV.  
Ysl.  
Species I.

Klaproth on the other hand found

59.75	yttria
21.25	silica
18.00	oxide of iron
0.50	alumina

---

99.50†

This last analysis does not differ much from that which Ekeberg had before published.

## ORDER II. SALINE STONES.

UNDER this Order I comprehend all the minerals which consist of an earthy basis combined with an acid. They naturally divide themselves into five genera. I shall describe them in the following order.

### I. CALCAREOUS SALTS.

1. Carbonat of lime,
2. Sulphat of lime,
3. Phosphat of lime,
4. Fluat of lime,
5. Borat of lime,
6. Arseniat of lime.

Arrange-  
ment.

\* *Ann. de Chim.* xxxvi. 152.

† *Ibid.* xxxvii. 87.

Class I.  
Order II.

## II. BARYTIC SALTS.

1. Carbonat of barytes,
2. Sulphat of barytes.

## III. STRONTIAN SALTS.

1. Carbonat of strontian,
2. Sulphat of strontian.

## IV. MAGNESIAN SALTS.

Sulphat of magnesia.

## V. ALUMINOUS SALTS.

1. Alum,
2. Mellite,
3. Chriolite.

### GENUS I. CALCAREOUS SALTS.

This genus comprehends all the combinations of lime and acids which form a part of the mineral kingdom.

#### *Sp. I.* Carbonat of lime.

No other mineral can be compared with carbonat of lime in the abundance with which it is scattered over the earth. Many mountains consist of it entirely, and hardly a country is to be found on the face of the globe where, under the names of limestone, chalk, marble, spar, it does not constitute a greater or smaller part of the mineral riches.

Crystals.

It is often amorphous, often stalactical, and often crystallized. The primitive form of its crystals is a parallelepiped, whose sides are rhombs, with angles of  $77^{\circ} 30'$  and  $102^{\circ} 30'$ . Its integrant molecules have the same form. The varieties of its crystals amount to more than 40. For a description and figure of which the reader is referred to *Romé de Lisle* \* and *Haüy* †.

\* *Crystallog.* i. 497.

† *Essai d'une Théorie*, &c. p. 75.—*Jour. de Phys.* 1793, August, p. 114.

When crystallized, its texture is foliated; when amorphous, its texture is sometimes foliated, sometimes striated, sometimes granular, and sometimes earthy. Its lustre varies from 0 to 3. Transparency from 0 to 4. It causes double refraction; and it is the only mineral which causes double refraction through two parallel faces of the crystal. Hardness from 3 to 9. Specific gravity from 2.315 to 2.78. Colour, when pure, white. Effervesces violently with muriatic acid, and dissolves completely, or leaves but a small residuum. The solution is colourless.

Genus I.  
Species I.  
Properties.

This species occurs in a great variety of forms; and therefore has been subdivided into numerous varieties. All these may be conveniently arranged under two general divisions.

#### I. Soft carbonat of lime.

*Variety 1.* Agaric mineral. *Mountain milk*, or *mountain meal* of the Germans.—This variety is found in the clefts of rocks, or the bottom of lakes. It is nearly in the state of powder; of a white colour, sometimes with a shade of yellow; and so light that it almost floats on water.

*Variety 2.* Chalk.—The colour of chalk is white, sometimes with a shade of yellow. Lustre 0. Opaque. Hardness 3 to 4. Specific gravity from 2.315 to 2.657. Texture earthy. Adheres slightly to the tongue. Feels dry. Stains the fingers, and marks. Falls to powder in water. It generally contains about  $\frac{2}{100}$  of alumina, and  $\frac{3}{100}$  of water; the rest is carbonat of lime.

*Variety 3.* Arenaceous limestone.—Colour yellow.

—*Jour. de Hist. Nat.* 1792, February, p. 148.—*Ann. de Chim.* xvii. 249.  
&c.—*Jour. de Min.* No. xxviii. 304.

Class I.  
Order II.

ish white. Lustre 1. Transparency 1. So brittle that small pieces crumble to powder between the fingers. Specific gravity 2.742. Phosphoresces in the dark when scraped with a knife, but not when heated. It consists almost entirely of pure carbonat of lime.

*Variety 4.* Testaceous tufa.—The colour of this variety is yellowish or greyish white. It is exceedingly porous and brittle; and is either composed of broken shells, or resembles mortar containing shells; or it consists of fistulous concretions variously ramified, and resembling moss.

## II. Indurated carbonat of lime.

*Variety 1.* Compact limestone.—The texture of this variety is compact. It has little lustre; and is most commonly opaque. Hardness 5 to 8. Specific gravity 1.3864 to 2.72. Colour grey, with various shades of other colours. It most commonly contains about  $\frac{1}{10}$ th of alumina, oxyd of iron, &c.; the rest is carbonat of lime. This variety is usually burnt as lime.

*Variety 2.* Granularly foliated limestone.—Structure sometimes slaty. Texture foliated and granular. Lustre 2 to 1. Transparency 2 to 1. Hardness 7 to 8. Specific gravity 2.71 to 2.8376. Colour white, of various shades from other colours.

*Variety 3.* Sparry limestone.—Structure sparry. Texture foliated. Fragments rhomboidal. Lustre 2 to 3. Transparency from 2 to 4; sometimes 1. Hardness 5 to 6. Specific gravity from 2.693 to 2.718. Colour white: often with various shades of other colours. To this variety belong all the crystals of carbonat of lime.

*Variety 4.* Striated limestone.—Texture striated or fibrous. Lustre 1 to 0. Transparency 2 to 1. Hard-

ness 5 to 7. Specific gravity commonly from 2.6 to 2.77. Colour various.

*Variety 5.* Swine stone.—Texture often earthy. Fracture often splintery. Lustre 1 to 0. Transparency 0 to 1. Hardness 6 to 7. Specific gravity 2.701 to 2.7121. Colour dark grey, of various shades. When scraped or pounded, it emits an urinous or garlic smell.

*Variety 6.* Oviform—This variety consists of a number of small round bodies, closely compacted together. Lustre 0. Transparency 0 or 1. Hardness 6 to 7.

*Sp. 2.* Sulphat of lime.

*Gypsum—Selenite.*

This mineral is found abundantly in Germany, France, England, Italy, &c.

It is found sometimes in amorphous masses, sometimes in powder, and sometimes crystallized. The primitive form of its crystals, according to Romé de Lisle, is a dodecahedron, which may be conceived as two four-sided pyramids, applied base to base, and which, instead of terminating in pointed summits, are truncated near their bases; so that the sides of the pyramids are trapeziums, and they terminate each in a rhomb. These rhombs are the largest faces of the crystal. The angles of the rhombs are  $52^{\circ}$  and  $158^{\circ}$ . The inclination of two opposite faces of one pyramid to the two similar faces of the other pyramid is  $145^{\circ}$ , that of the other faces 110°. Sometimes some of the faces are elongated: sometimes it crystallizes in six-sided prisms, terminated by three or four-sided summits, or by an indeterminate number of curvilinear faces. For a descrip-

Crystals.

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\* *Crystallog.* i. 144.



Class I.  
Order II.

Properties

tion and figure of these varieties, the reader is referred to Romé de Lisle\*.

The texture of sulphat of lime is most commonly foliated. Lustre from 0 to 4. Transparency from 0 to 4. It causes double refraction. Its hardness does not exceed 4. Its specific gravity from 1.872 to 2.311. Colour commonly white or grey.

Before the blow-pipe it melts into a white enamel, provided the blue flame be made to play upon the edges of its laminæ. When the flame is directed against its faces, the mineral falls into powder†.

It does not effervesce with muriatic acid, except it be impure; and it does not dissolve in it.

The following varieties of this mineral are deserving of attention.

Varieties.

*Variety 1.* Broad foliated sulphat.—Texture broad foliated. Lustre glassy, from 4 to 2. Transparency from 4 to 3. Hardness 4. Specific gravity 2.311. Colour grey, often with a shade of yellow.

*Variety 2.* Grano-foliated sulphat.—Texture foliated, and at the same time granular; so that it easily crumbles into powder. Lustre 2 to 3. Transparency 2 to 3. Hardness 4 to 3. Specific gravity from 2.274 to 2.310. Feels soft. Colour white or grey, often with a tinge of yellow, blue, or green; sometimes flesh red, brown, or olive green.

*Variety 3.* Fibrous sulphat.—Texture fibrous. Fragments long splintery. Lustre 2 to 3. Transparency 2 to 1; sometimes 3. Hardness 4. Brittle. Specific gravity 2.300. Colour white, often with a shade of grey, yellow, or red; sometimes flesh red, and some-

\* *Crystallog.* i. 144.

† Le Lievre, *Jour. de Min.* No. xxviii. 315.

times honey yellow; sometimes several of these colours meet in stripes.

*Variety 4.* Compact sulphat.—Texture compact. Lustre 1 or 0. Transparency 2 to 1, sometimes 0. Hardness 4. Specific gravity from 1.872 to 2.288. Feels dry but not harsh. Colour white, with a shade of grey, yellow, blue, or green; sometimes yellow; sometimes red; sometimes spotted, striped, or veined.

*Variety 5.* Farinaceous sulphat.—Of the consistence of meal. Lustre 0. Opaque. Scarcely sinks in water. Is not gritty between the teeth. Feels dry and meagre. Colour white. When heated below redness, it becomes of a dazzling white.

*Sp. 3.* Phosphat of lime.

*Apatite—Phosphorite—Cbrysolite* of the French.

This substance is found in Spain, where it forms whole mountains, and in different parts of Germany. It is sometimes amorphous, and sometimes crystallized. The primitive form of its crystals is a regular six-sided prism. Its integrant molecule is a regular triangular prism, whose height is to a side of its base as 1 to  $\sqrt{2}$  \*. Sometimes the edges of the primitive hexagonal prism are wanting, and small faces in their place; sometimes there are small faces instead of the edges which terminate the prism; sometimes these two varieties are united; sometimes the terminating edges and the angles of the prism are replaced by small faces; and sometimes the prism is terminated by four-sided pyramids †.

Crystal.

Its texture is foliated. Its fracture uneven, tending to conchoidal. External lustre from 2 to 3; internal, 3 to 2. Transparency from 4 to 2. Causes single re-

Properties.

\* Haüy, *Jour. de Min.* No. xxviii. 310.

† Haüy, *Ibid.*

Class I.  
Order II.

fraction. Hardness 6 to 7. Brittle. Specific gravity from 2.8249 to 3.218. Colour commonly green or grey; sometimes brown, red, blue, and even purple.

It is infusible by the blow-pipe. When its powder is thrown upon burning coals, it emits a yellowish green phosphorescent light. It is soluble in muriatic acid without effervescence or decomposition, and the solution often becomes gelatinous.

*Sp. 4. Fluat of lime.*

*Fluor.*

This mineral is found abundantly in different countries, particularly in Derbyshire. It is both amorphous and crystallized.

Crystals.

The primitive form of its crystals is the regular octahedron; that of its integrant molecules the regular tetrahedron\*. The varieties of its crystals hitherto observed amount to 7. These are the primitive octahedron; the cube; the rhomboidal dodecahedron; the cubo-octahedron, which has both the faces of the cube and of the octahedron; the octahedron wanting the edges; the cube wanting the edges, and either one face, or two faces in place of each. For a description and figure of these, the reader is referred to Mr Haüy†.

Properties.

The texture of fluat of lime is foliated. Lustre from 2 to 3, sometimes 0. Transparency from 2 to 4, sometimes 1. Causes single refraction. Hardness 8. Very brittle. Specific gravity from 3.0943 to 3.1911. Colours numerous, red, violet, green, red, yellow, blackish purple. Its powder thrown upon hot coals emits a bluish or greenish light. Two pieces of it rubbed in the

\* Haüy, *Jour de Min.* No. xxviii. 325.

† Ibid.

dark phosphoresce. It decrepitates when heated. Before the blow-pipe it melts into a transparent glass\*.

Genus I.  
Species V.

It admits of a polish, and is often formed into vases and other ornaments.

*Sp. 5. Borat of lime.*

*Boracite.*

This mineral has been found at Kalkberg near Luneburg, seated in a bed of sulphat of lime. It is crystallized. The primitive form of its crystals is the cube †. In general, all the edges and angles of the cube are truncated; sometimes, however, only the alternate angles are truncated ‡. The size of the crystals does not exceed half an inch.

Crystals.

The texture of this mineral is compact. Its fracture is flat conchoidal. External lustre 3; internal, greasy, 2. Transparency from 2 to 3. Hardness 9 to 10. Specific gravity 2.566. Colour greyish white, sometimes passing into greenish white or purplish.

Properties.

When heated it becomes electric; and the angles of the cube are alternately positive and negative §.

Before the blow-pipe it froths, emits a greenish light, and is converted into a yellowish enamel, garnished with small points, which, if the heat be continued, dart out in sparks ||.

According to Westrum, who discovered its component parts, it contains

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\* Haüy, *Jour. de Min.* No. xxviii. 325.

† Haüy, *Ibid.*

‡ Haüy and Westrum.

§ Haüy, *Ibid.* and *Ann. de Chim.* ix. 59.

|| Le Lievre, *Jour. de Min.* *Ibid.*

Class I.  
Order II.

Composi-  
tion.

68 boracic acid

13.5 magnesia

11 lime

1 alumina

2 silica

1 iron

---

96.5\*

*Sp. 6.* Arseniat of lime.

*Pharmacolite* of Kärsten.

Found in the Furstemberg of Wittichen in tubercles or small capillary crystals united in bundles. Colour snow white. Lustre silky. Texture fibrous; fibres diverging. Transparency of the crystals 4. Very friable. Klaproth found it composed of lime, arsenic acid, and a little cobalt.

*Sp. 7.* Nitrat of lime.

Found abundantly mixed with native nitre. For a description see Volume II. p. 300.

## GENUS II. BARYTIC SALTS.

This genus comprehends the combinations of barytes with acids.

*Sp. 1.* Carbonat of barytes.

*Witherite.*

Crystals. This mineral was discovered by Dr Withering; hence Werner has given it the name of *witherite*. It is found both amorphous and crystallized. The crystals are octahedrons or dodecahedrons, consisting of four or six sided pyramids applied base to base; sometimes the six-sided pyramids are separated by a prism; sometimes

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\* *Ann. de Chim.* ii 116.



several of these prisms are joined together in the form of a star.

Genus II.  
Species II.

Its texture is fibrous. Its fracture conchoidal. Its fragments long splintery. Lustre 2. Transparency 2 to 3. Hardness 5 to 6. Brittle. Specific gravity 4.3 to 4.338. Colour greenish white. When heated it becomes opaque. Its powder phosphoresces when thrown on burning coals\*.

Properties.

It is soluble with effervescence in muriatic acid. The solution is colourless.

According to Pelletier it contains

62 barytes  
22 carbonic acid  
16 water

Composi-  
tion,

100†

*Sp. 2. Sulphat of barytes.*

*Boroselenite.*

This mineral is found abundantly in many countries, particularly in Britain. It is sometimes in powder, often in amorphous masses, and often crystallized. The primitive form of its crystals is a rectangular prism, whose bases are rhombs, with angles of  $101^{\circ} 30'$  and  $78^{\circ} 30' \dagger$ . The varieties of its crystals are very numerous. For a description and figure of them I refer to Romé de Lisle§ and Haüy||. The most common varieties are the octahedron with cuneiform summits, the six or four sided prism, the hexangular table with bevelled edges. Sometimes these crystals are needleform.

Crystals.

\* Haüy.

† *Jour. de Min.* xxi. 46.

‡ Haüy, *Essai d'une Théorie*, p. 119.

§ *Crystal.* i. 588.

|| *Ibid.* and *Ann. de Chim.* xii. 3.

Class I.  
Order II.  
Properties.

Its texture is commonly foliated. Lustre from 0 to 2. Transparency from 2 to 0; in some cases 3 or 4. Hardness from 5 to 6. Specific gravity from 4.4 to 4.44. Colour commonly white, with a shade of yellow, red, blue, or brown.

When heated it decrepitates. It is fusible *per se* by the blue flame of the blow-pipe, and is converted into sulphuret of barytes. Soluble in no acid except the sulphuric; and precipitated from it by water.

Varieties.

*Variety 1.* Foliated sulphat.—Lustre 3 to 2. Transparency from 4 to 2, sometimes 1. Colours white, reddish, bluish, yellowish, blackish, greenish. Mr Werner subdivides this variety into three, according to the nature of the texture. These three subdivisions are *granularly foliated*, *straight foliated*, *curve foliated*.

*Variety 2.* Fibrous sulphat.—Texture fibrous; fibres converging to a common centre. Lustre silky or waxy, 2. Transparency 2 to 1. Hardness 5. Colours yellowish, bluish, reddish.

*Variety 3.* Compact sulphat.—Texture compact. Lustre 0 to 1. Transparency 1 to 0. Feels meagre. Almost constantly impure. Colours light yellow, red, or blue.

*Variety 4.* Earthy sulphat.—In the form of coarse dusty particles, slightly cohering. Colour reddish or yellowish white.

### GENUS III. STRONTIAN SALTS.

This genus comprehends all the combinations of strontian and acids which form a part of the mineral kingdom.

#### *Sp. 1.* Carbonat of Strontian.

This mineral was first discovered in the lead mine of

Strontian in Argyleshire; and since that time it is said to have been discovered, though not in great abundance, in other countries. It is found amorphous, and also crystallized in needles, which, according to Haüy, are regular six-sided prisms.

Genus III.  
Species II.

Its texture is fibrous; the fibres converge. Fracture uneven. Lustre 2. Transparency 2. Hardness 5. Specific gravity from 3.4 to 3.66. Colour light green. Does not decrepitate when heated. Before the blow-pipe becomes opaque and white, but does not melt. With borax it effervesces, and melts into a transparent colourless glass. Effervesces with muriatic acid, and is totally dissolved. The solution tinges flame purple.

Properties.

*Sp. 21.* Sulphat of strontian.

*Celestine.*

This mineral has been found in Pennsylvania, in Germany, in France, in Sicily, and Britain. It was first discovered near Bristol by Mr Clayfield. There it is found in such abundance, that it has been employed in mending the roads.

It occurs both amorphous and crystallized. The crystals are most commonly bevelled tables, sometimes rhomboidal cubes. Its texture is foliated. More or less transparent. Hardness 5. Specific gravity from 3.51 to 3.96. Colour most commonly a fine sky blue; sometimes reddish; sometimes white, or nearly colourless\*.

Properties.

Klaproth found a specimen of this mineral from Pennsylvania composed of

58 strontian
42 sulphuric acid

Composition.

100†

\* Clayfield, Nicholson's *Jour.* iii. 36.

† Beitrage, ii. 97.

Class I.  
Order II.

According to the analysis of Mr Clayfield, the sulphat of strontian found near Bristol is composed of

58.25 strontian

41.75 sulphuric acid of 2.24, and a little iron \*.

---

100.00

According to the analysis of Vauquelin, the sulphat of strontian found at Bouvron in France, which was contaminated with .1 of carbonat of lime, is composed of . . . . . 54 strontian

45 sulphuric acid

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99 †

#### GENUS IV. MAGNESIAN SALTS.

*Sp. 1.* Sulphat of magnesia.

*Sp. 2.* Niträt of magnesia.

These salts are found in different countries, either sparingly mixed with the soil, or efflorescing upon walls, or dissolved in mineral waters. I have mentioned them merely in compliance with the custom of mineralogists: for they ought not, strictly speaking, to be ranked among minerals. For a description of them, I refer to the First Part of this Work ‡.

#### GENUS V. ALUMINOUS SALTS.

This genus comprehends all the combinations of alumina with acids, which constitute a part of the mineral kingdom. Hitherto only three species have occurred.

*Sp. 1.* Alum.

This salt is found in crystals, in soft masses, in flakes,

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\* Clayfield, Nicholson's *Jour.*

† *Jour de Min.* No. xxxvii. 6.

‡ See vol. ii. p. 267. and 305.

and invisibly mixed with the soil. For a description, I refer to Vol. II. p. 272.

Genus V.  
Species II.

Sp. 2. Mellite\*.

*Honeystone—Mellat of Alumina.*

This mineral was first observed about ten years ago in Thuringia, between the layers of wood-coal. It is of a honey-yellow colour (hence its name), and is usually crystallized in small octahedrons, whose angles are often truncated. Lustre 2 to 3. Transparency considerable. Properties. Fracture conchoidal. Hardness 5. Specific gravity, according to Abich, 1.666. When heated it whitens; and in the open air burns without being sensibly charred. A white matter remains, which effervesces slightly with acids, and which at first has no taste, but at length leaves an acid impression upon the tongue.

Abich shewed that it is composed chiefly of alumina and an acid which exhibited some of the properties of the benzoic. This analysis was repeated by Klaproth, who found the mellite composed of alumina and a peculiar acid to which he gave the name of *mellitic acid*. Analysis. Vauquelin obtained the same result. The mellitic acid has several properties in common with the oxalic, which induced him at first to consider it as the same with that acid. But Klaproth has since demonstrated that it is different.

The *mellitic acid*, when exposed to heat, is decomposed very speedily, and evaporates in a thick grey smoke. Mellitic acid. When distilled it yields a great quantity of carbonic acid. It combines in excess with potass, and forms a super-mellat, which has a slightly acid taste, is sparingly

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\* Emmerling's *Lehrbuch*, ii. 89.—Wiedeman's *Hanbuch*, p. 639.—Abich, *Crell's Annals*, 1797, ii. 3.—Vauquelin, *Ann. de Chim.* xxxvi. 23.—Klaproth, *Ibid.* xxxvii. 88.—Kirwan's *Min.* ii. 68. Karsten, *Mus. Leck.* ii. 335.



Class I.  
Order II.

soluble in water, and crystallizes. When this salt is poured into a solution of sulphat of alumina, it occasions a flaky precipitate; whereas super-oxalat of potass occasions none.

Sp. 3. Chriolite\*.

*Sulphat of soda-and-alumina.*

Properties.

This mineral has hitherto been found in Greenland only; from which it was brought to Copenhagen, where it lay eight or nine years unnoticed, till at last it was analysed by Abelgaard. The primitive form of its crystals seems to be an octahedron, whose faces are isosceles triangles. Its colour is snow white. Texture foliated. Hardness inferior to that of fluat of lime. Specific gravity 2.949. Melts before it reaches a red heat, and when simply exposed to the flame of a candle †. Abelgaard analysed it, and obtained fluoric acid and alumina. Klaproth has lately proved that it contains also soda. The result of his analysis is as follows:

Composition.

40.5 fluoric acid and water  
36.0 soda  
23.5 alumina

---

100.0

This analysis has been confirmed by Vauquelin.

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\* *Ann. de Chim.* xxvii. 87. and 89.—*Jour. de Phys.* lii. 35.—Hauy, *Ibid.* xlix. 462.

† Hence its name from *κρως* and *λιθος*, as if it melted as easily as ice.

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END OF THE THIRD VOLUME.

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Fig. 16.

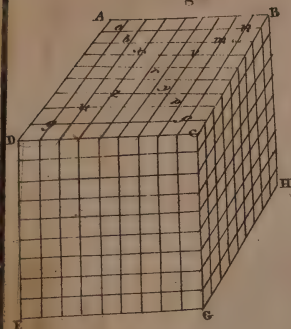


Fig. 17.

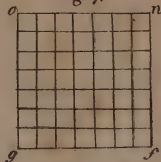


Fig.18.

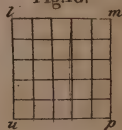


Fig 19.



**Fig20.**



Fig:21.

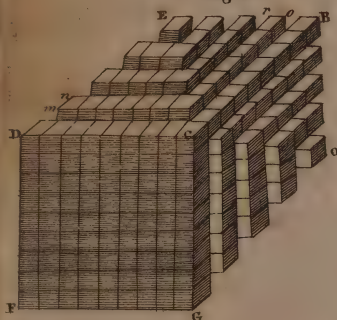


Fig 22.

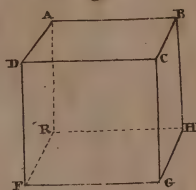


Fig. 23.

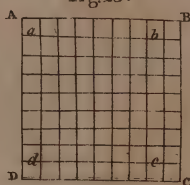


Fig.24.

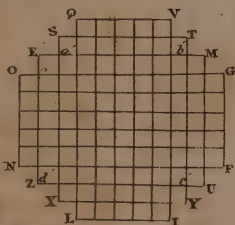


Fig. 25.

